AD/A-006 203

THE INTERNATIONAL GRAVITY STANDARDIZATION NET 1971 (I.G.S.N.71)

C. Morelli, et al

Osservatorio Geofisico Sperimentale

Prepared for:

Air Force Cambridge Research Laboratories
European Office of Aerospace Research and Development

31 May 1972

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. Report Number Contract AF61(052)656	2. Govt Accession No.	3. Recipient's Catalog Number AD/A006 203
4. Title (and Subtitle) THE INTERNATIONAL GRAVITY STANDARDIZATION NET 1971 (I.G.S.N.71)		5. Type of Report & Period Covered Final Scientifi· ᵓeport 1 Nov 1962 - 3C ˜ 1970 6. Performing Org. ·: Number
7. Author(s) C. Morelli, C. Gantar, ~~T. Honkasalo~~, R.K.McConnell, B. Szabo, ~~J. Tanner~~, U Uotila ~~& G. Whalen~~		8. Contract or Grant Number AF61(052)-656
9. Performing Organization Name and Address Osservatorio Geofisico Sperimentale Viale R. Gessi 4 34123 Trieste, Italy		10. Program Element, Project, Task Area & Work Unit Numbers 7600-02 62405394 681000
11. Controlling Office Name and Address Air Force Cambridge Research Laboratories/LW L.G. Hanscom AFB, Bedford, MA 01730		12. Report Date 31 May 1972 13. Number of Pages 194
14. Monitoring Agency Name and Address EOARD/NRP, Box 14 FPO New York 09510		15.

16. & 17. Distribution Statement

Approved for public release; distribution unlimited.

18. Supplementary Notes

Tech, other

19. Key Words

GRAVITY VALUES	ADJUSTMENT	ABSOLUTE GRAVITY
STANDARDIZATION	PENDULUMS	
REFERENCE SYSTEM	GRAVIMETERS	

20. Abstract A worldwide network, consisting of 24 000 gravimeter, 1 200 pendulum and 10 absolute measurements collected over twenty years has been adjusted by a small Working Group of Special Study Group 5 of the International Association of Geodesy, discussed and approved within the same Association and adopted at the XV Assembly of the IUGG in Moscow, Aug 1971. The concept differs from that of earlier gravity reference systems in that datum is determined not by an adopted value at a single station, but by the gravity values for 1854 stations obtained from a single least squares adjustment of absolute, pendulum and gravimeter data. Standard errors for IGSN 71 gravity values are less than ± 0.1 mgal. The use and maintenance of the system is discussed. The International Gravity Standardization Net 1971 has been approved and adopted as the international gravity standard replacing the Potsdam datum.

FORM 1473

UNION GEODESIQUE ET GEOPHYSIQUE INTERNATIONALE
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

ASSOCIATION INTERNATIONALE DE GEODESIE
INTERNATIONAL ASSOCIATION OF GEODESY

PUBLICATION SPECIALE N° 4

THE INTERNATIONAL GRAVITY STANDARDIZATION NET 1971

(I.G.S.N.71)

Préparé par le Professeur C. MORELLI

Publié par le

BUREAU CENTRAL
DE L'ASSOCIATION INTERNATIONALE DE GEODESIE
19, rue Auber – 75009 PARIS

2

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

INTERNATIONAL ASSOCIATION OF GEODESY

THE INTERNATIONAL GRAVITY STANDARDIZATION NET 1971

(I.G.S.N. 71)

by

C. Morelli
C. Gantar — *Osservatorio Geofisico Sperimentale, Trieste – ITALY*

T. Honkasalo — *Geodeetinen Laitos, Helsinki – FINLAND*

R.K. McConnell
J.G. Tanner — *Earth Physics Branch, Gravity Div. Dept. of Energy, Mines and Resources, Ottawa CANADA*

B. Szabo — *Air Force Cambridge Research Laboratories, Bedford, Mass., U.S.A.*

U. Uotila — *Dept. of Geodetic Science, Ohio State Univ., Columbus, Ohio, U.S.A.*

C.T. Whalen — *1st Geodetic Survey Squadron of A.C.S. and M.A.C., Cheyenne, Wyo., U.S.A.*

ABSTRACT

The International Gravity Standardization Net 1971 is presented. A worldwide network, consisting of 24 000 gravimeter, 1 200 pendulum and 10 absolute measurements collected over twenty years, has been adjusted by a small Working Group of Special Study Group 5 of the International Association of Geodesy, discussed and approved within the same Association and adopted at the XV General Assembly of the International Union of Geodesy and Geophysics in Moscow, Aug 1971.

The concept of the IGSN 71 differs from that of earlier gravity reference systems in that datum is determined, not by an adopted value at a single station, but by the gravity values for 1854 stations obtained from a single least squares adjustment of absolute, pendulum and gravimeter data. Standard errors for IGSN 71 gravity values are less than ± 0.1 mgal. The use and maintenance of the system is discussed.

The International Gravity Standardization Net 1971 has been approved and adopted as the international gravity standard replacing the Potsdam datum. The resolution passed at the XV General Assembly of the IUGG in Moscow, August 1971 is given below :

RESOLUTION N° 11

The International Union of Geodesy and Geophysics,

recognizing that the Potsdam datum adopted in London in 1909, has served its purpose in providing a reference for international gravity measurements,

considering

a) that for scientific purposes a more accurate system of gravity values is needed to provide both datum and scale,

b) that the IAG has adopted at the Lucerne General Assembly in 1967 a provisional correction of - 14 mGal to the Potsdam value (Resolution n° 22),

c) that the International Committee on Weights and Measures adopted in 1967 a resolution for a correction of - 14 mGal to the values of gravity in the Potsdam datum to be used for metrological purposes,

d) that recent absolute, pendulum and gravimeter observations have provided a firm basis for the determination of datum and scale to the required accuracy,

e) that the above mentioned measurements have been adjusted to provide a homogeneous International Gravity Standardization Net (IGSN 71) which defines the datum and scale and gives gravity values with the same order of accuracy throughout its range,

f) that the establishment of such a system represents a major international effort, and provision for maintenance and improvement must be made,

g) that the accuracy of the absolute determination of gravity is adequate for studies of variations in the distribution and displacements of masses, and variations of G,

recommends

(i) that the International Gravity Standardization Net 1971 (IGSN 71) be adopted and published in the Bulletin Géodésique,

(ii) that the Potsdam datum be corrected by the amount specified in the adjustment

°

° °

LIST OF ABBREVIATIONS AND SYMBOLS

ACL	American Calibration Line
ACS	American Calibration System
AFCRL	Air Force Cambridge Research Laboratories, Bedford, Mass., U.S.A.
AMS	Army Map Service (now : TOPOCOM), U.S.A.
ASCL	American Secondary Calibration Line
BEV	Bundesamt für Eich-und-Vermessungswesen, Wien, Austria.
BGI	Bureau Gravimétrique International, Paris, France.
BIPM	Bureau International Poids et Mesures, Sèvres, France.
BMR	Bureau of Min. Res., Geol. and Geophys., Melbourne, Australia.
CASCL	Central Asia Secondary Calibration Line
CGI	Commissione Geodetica Italiana, Roma, Italy.
CU	Cambridge University, U.K.
DGFI	Deutsch. Geodätisches Forschungsinstitut, München, Germany.
DO	Dominion Observatory, Ottawa, Canada (now : EPB).
EACL	Euro-African Calibration Line
EACS	Euro-African Calibration System
EASCL	Euro-African Secondary Calibration Line
ECCL	East Coast Calibration Line (U.S.A.)
ECL	European Calibration Line
EPB	Earth Physics Branch, Gravity Division, Dept. of Energy, Mines and Resources, Ottawa, Canada.
EPF	Expéditions Polaires Françaises
FOWGN	First Order World Gravity Net
GIA	Geological Institut, Aarhus, Denmark.
GIH	Geodätisches Institut Hanover, Germany, Fed. Rep.
GL	Geodeettinen Laitos, Helsinki, Finland.
GSI	Geographical Survey Institute, Tokyo, Japan.
HIG	Hawaii Institute of Geophysics, Honolulu, U.S.A.
IAG	International Association of Geodesy
IAGS	Inter American Geodetic Survey
IGB	International Gravity Bureau
IGC	International Gravity Commission
IGPM	Istituto di Geodesia del Politecnico, Milano, Italy.
IGS	Institute of Geological Sciences, London, U.K. (formerly : OGS)
IGSN 71	International Gravity Standardization Net 1971
ITGH	Institut für Theoretische Geodäsie, Technische Hochschule, Hanover, Germany.
IUGG	International Union of Geodesy and Geophysics
LCR	LaCoste and Romberg gravimeter (general name)
NACL	North American Calibration Line
NAVOCEANO	formerly : USNOO

NGBN	National Gravity Base Net, U.S.A.
NOS	U.S. National Ocean Survey (formerly USCGS)
OGS	Overseas Geological Survey, London, U.K. (now : IGS = Institute of Geological Sciences)
OGST	Osservatorio Geofisico Sperimentale, Trieste, Italy.
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer, Paris, France.
OSU	Ohio State Univ., Dept. of Geodetic Science, Columbus, Ohio, U.S.A.
THA	Technische Hochschule, Aachen, Germany.
TOPOCOM	U.S. Army Topographic Command, Washington, D.C., U.S.A. (formerly : AMS)
UBA	Universidad de Buenos Aires, Argentina.
UNAM	Universidad Autonoma de Mexico, Mexico City, Mexico.
USCGS	U.S. Coast and Geodetic Survey, Washington, D.C. U.S.A. (now : NOS)
USNOO	U.S. Naval Oceanographic Office, Washington, D.C., U.S.A. (now: NAVOCEANO)
UW	University of Wisconsin, Madison, Wisc., U.S.A.
WPCL	West Pacific Calibration Line
1GSSq	1st Geodetic Survey Squadron of ACGS (Aerospace Cartographic and Geodetic Service) and MAC (Military Airlift Command), Cheyenne, Wyo., U.S.A. (formerly : 1381GSSq)
1381GSSq	1381st Geodetic Survey Squadron of APCS (Air Photographic and Charting Service), Orlando, Fla., U.S.A. (now : 1GSSq).

o

o o

TABLE OF CONTENTS

1. – INTRODUCTION

1.1. Concepts

Metrology, geodesy and geophysics require the knowledge of gravity with great accuracy all over the earth. Programs to provide gravity measurements on land, on the continental shelves and on the oceans have expanded rapidly and we are close to achieving airborne gravity measurements with the desired accuracy. A homogeneous world-wide gravity reference system is therefore required in order to standardize these measurements. This new system should give datum and scale with an accuracy compatible with the modern instrumental capability.

The Potsdam gravity system specified a datum only in terms of an absolute gravity value at a single point. Individual gravity values in the system were determined by adjusting a network of absolute gravity differences measured with pendulums and tied to this datum point. The introduction of the modern gravimeter capable of measuring gravity differences with high internal consistency, but in relative units only, indicated the presence of errors in pendulum measurements which could, in the absence of highly repetitive data, significantly affect the determination of scale. The ease of portability of the gravimeter led to the concept of establishing separate calibration lines combining pendulum and gravimeter measurements to determine the scale calibration factor for each gravimeter. The gravimeters could then in principle be used to measure gravity differences elsewhere in the world network. Several calibration lines were established for this purpose but significant scale differences between them were later identified. Modern absolute instrumentation for the first time permitted the development of the concept presented in this report : using a suitable mathematical model we may now combine absolute, pendulum and gravimeter measurements to obtain the most probable gravity values for the world reference system in which the most probable value of datum and scale is implicit.

1.2. Evolution of world gravity standards

1.2.1. Early development

The first internationally accepted gravity reference system was known as the *Vienna Gravity System* . It was adopted in 1900 at the XIIIth Conference of the International Association of Geodesy held in Paris and had an estimated relative accuracy of ± 10 mGal.

The *Potsdam Gravity System* was introduced soon after (Borass, 1911) and internationally accepted at the 1909 meeting of the I.A.G. in London. The relative accuracy of this system was estimated at ± 3 mGal and it corrected the Vienna System by - 16 mGal. Absolute gravity measurements in the past few decades (Heyl, Cook, 1936; Clark, 1939) indicated an error of + 12 to + 16 mGal in the absolute Potsdam value (Dryden, 1942; Morelli, 1946a; Berroth, 1949; Preston Thomas et al., 1960; Cook, 1965a).

By the end of World War II it was evident that not only more absolute measurements but also an interconnecting net of relative gravity ties were required to define a new gravity system.

The publication of two independent adjustments (Morelli, 1946a; Hirvonen, 1948) demonstrated the insufficient distribution and accuracy of the existing gravity measurements and induced G. P. Woollard to undertake his pioneer work of promoting the geodetic use of new instruments (Worden and LaCoste-Romberg gravimeters, Gulf pendulums) to provide new and more accurate relative gravity measurements all over the world (Woollard and Rose, 1963).

By the early 1950's many agencies had become involved in long range gravimeter and pendulum measurements, inhomogeneity in the distribution of stations, in observational criteria and techniques and in data reduction methods necessitated the coordination of these activities. Accordingly action was taken through the IGC of the I.A.G. and in 1954 the Special Study Group n° 5 (SSG 5) was formed with responsibilities in the following fields :

(a) Absolute measurements of gravity
(b) Network connections
(c) International Gravity Formula.

A network of 34 stations to be known as the First Order World Gravity Net were chosen at the 1956 meeting of the IGC in Paris and plans were made to concentrate on gravity connections between them. These stations were :

Algiers	Khartoum	Oslo
Azores	Kyoto	Ottawa
Bad Harzburg	Leopoldville	Panama
Beirut	Lisbon	Paris
Buenos Aires	Madison	Potsdam
Capetown	Madrid	Quito
Christchurch	M'Bour-Dakar	Reykjavik
Fairbanks	Melbourne	Rio de Janeiro
Helsinki	Mexico City	Singapore
Honolulu	Milan	Teddington
Johannesburg	New Delhi	Vancouver
		Washington

During the next 8 or 9 years relative gravity measurements were carried out on a world-wide basis by many observers. For logistic and technical reasons it was often impractical to carry out direct interconnection of the FOWGN stations and a large number of inhomogeneous subnets came into existence. Apart from partial solutions such as the basic world-wide work of Woollard and Rose (1963), the least squares adjustment by Uotila (1964) and the European Calibration System (Kneissl, Marzahn, 1963) the evolution of a new world gravity system proceeded slowly. Some significant improvements in instrumentation occurred during this period, e.g. development of the LCR gravimeter, but some disturbing aspects of the performance of pendulum apparatuses came to light. The apparent state of the art was summarized (Morelli, 1963) as follows :

" a) Modern pendulum results, previously considered fairly reliable, have revealed (Woollard and Rose, 1963) tares and creep : that is, the same weak points as the gravity-meters; pendulums should therefore always be used in connection with properly chosen and studied gravity-meters;

b) Results with modern, geodetic gravity-meters have shown that it may also be possible to measure large differences in gravity, provided that :

(1) they are operated in groups to control tares and creep;

(2) they are properly checked in the laboratory and on the calibration lines to detect and evaluate pseudo-periodic errors and nonlinearity;

(3) they are calibrated (on sufficiently accurate and extended calibration lines) to determine their scale-factor function.

It is well known that normally (3) can be done only by comparison with pendulum measurements.

It would seem that a solution would be impossible : we need the gravity-meters to be sure of the pendulums and the pendulums to calibrate the gravity-meters.

Without proper consideration of this point, it is clear that confusion and uncertaintly has been and will continue to be created. This is the reason that we do not have a "World Standardization System", although we have many "Calibration Systems": referred to different pendulum apparatus, or to different pendulum results, or to a different evaluation of the same pendulum measurements".

1.2.2. Modern Development

The above situation led the SSG5 during the 1962 Meeting of I.G.C. to propose, and the I.G.C. to accept, a new philosophy as follows :

I. The establishment of three International Calibration Lines, with large gravity intervals.

They were :

the ACL	from Ushuaia to Point Barrow;
the EACL	from Capetown to Hammerfest;
the WPCL	from Christchurch to Sapporo.

Groups of gravimeters were to be observed on these lines.

II. The selection of a few stations on each International Calibration Line to be occupied by the best available pendulum apparatus using the same operational criteria. The chosen apparatuses were :

the Gulf pendulums;

the Cambridge pendulums;

the CGI pendulums;

the GSI pendulums.

III. Interconnection would be established between the Lines for strengthening the structure and establishing the skeleton of the world net.

To further coordinate the collection and reduction of data for the preparation of a final adjustment, the SSG5 formed a sub-group of specialists devoted to the solution of specific problems. The representatives of the institutions most actively participating met for the first time in 1965 in Torino, Italy, and formed a permanent Working Sub-Group, under the chairmanship of Prof. C. Morelli.

In the next few years most of the measurements required for a new reference system were carried out. Important contributions were made by 1381GSSq with the first systematic global LaCoste and Romberg gravimeter measurements (Whalen 1965a, 1965b, 1966b, 1966c, 1967a, 1967b) and by AFCRL who supported many projects, especially pendulum and absolute measurements.

The accuracy of the gravimeter measurements (± 0.05 mGal) and the improved pendulum apparatus (± 0.3 mGal) made possible the attainment of a world network of high *relative* accuracy. The problem of obtaining high *absolute* accuracy, as well, was solved with the development of Cook's apparatus (± 0.1 mGal), Faller's transportable apparatus (± 0.05 mGal) and Sakuma's apparatus (± 0.03 mGal).

Significant progress in the development of data processing and analysis techniques were made by Hamilton (1963) and Torge (1966) The availability of large high-speed digital computers, the development of software for solving large systems of linear equations and for statistical analysis of large volumes of data permitted a new approach to the solution of a world-wide gravity net. The development of computer programs at the EPB employing iterative techniques for the solution of systems of linear equations in several thousand unknowns has facilitated the adjustment of large gravity nets.

The amount of new data and the dangers inherent in continuous disseminations of new values led the International Gravity Commission at its last meeting (Paris, 1970) to request that only one final adjustment should be published and internationally adopted. The present report describes the adjustments and analyses which produced the International Gravity Standardization Net 1971.

1.3. Summary of the work of SSG 5

Reports of the SSG5 have been presented and discussed at the following meetings :

1954, in Rome	- X IUGG General Assembly	(unp.)
1956, in Paris	- IGC Meeting	(unp.)
1957, in Toronto	- XI IUGG General Assembly	(see Morelli, 1959)
1959, in Paris	- IGC Meeting	(unp.)
1960, in Helsinki	- XII IUGG General Assembly	(unp.)
1962, in Paris	- IGC Meeting	(unp.)
1963, in Berkeley	- XIII IUGG General Assembly	(unp.)
1965, in Paris	- IGC Meeting	(unp.)
1967, in Lucerne	- XIV IUGG General Assembly	(unp.)
1970, in Paris	- IGC Meeting	(unp.)

Meeting of the Working Sub-Group have been held in :

- Torino,	April 1965;
- Paris,	September 1965;
- Bedford,	April 1967;
- Paris,	September 1970;
- Ottawa,	May 1971.

Some informations concerning the Group's activity and discussions at the IGC and IUGG Meetings are printed in the "Bulletin d'Information" of the IGB.

The members of the Sub-Group participating in the final adjustment and the presentation of this report are :

AFCRL	: B. Szabo	IGSSq	: C.T. Whalen
EPB	: R.K. McConnell, J.G. Tanner	OGST	: C. Gantar, C. Morelli
GL	: T. Honkasalo	OSU	: U. Uotila

Prof. Woollard contributed to the efforts of this Working Sub-Group but could not participate in the final adjustment or in the presentation of this report. Prof. Wolf acted from time to time as a consultant to the Sub-Group.

2. – DATA DESCRIPTION

Appendix I contains a detailed description of IGSN 71 data and instruments. Approximately 25,000 observations interconnecting 473 primary and 139816 excenter bases were used.

The acquisition of data for the IGSN 71 required cooperation between many countries. Agencies throughout the world collaborated on many surveys, assisted each other in obtaining entry permission for observers and exchanged data, station descriptions and instruments. Data from 184 surveys using 86 different instruments has been collected by the OGST who acted as the data coordinating agency for the project.

Table 2.1. shows the scope of the surveys contributing to the IGSN 71.

Absolute gravity determinations are shown as separate surveys in the table. Three absolute apparatuses were used although most of the data was obtained with the portable Faller - Hammond equipment.

Pendulum data was obtained with six types of instruments, the bulk of the data being obtained with the Gulf and Cambridge pendulums.

Five types of gravimeters were used in obtaining IGSN 71 data and as many as 13 gravimeters were used on a single survey. The IGSSq surveys, which provide the largest single contribution to the structure of IGSN 71, were always made with four or more LaCoste and Romberg gravimeters. The Worden, Askania, North American and Western gravimeter data were obtained from observations made on the European and African portions of IGSN 71. LaCoste and Romberg gravimeter data, obtained over the entire net, provided the greatest contribution to the relative net strength.

For the adjustment of the IGSN 71, the absolute data provided the datum and contributed to scale, the pendulum data contributed to scale and the gravimeter data gave the basic structure of the net.

Table 2.1.

IGSN 71 instruments and data

Instrument	*Type instrument*	*N° instruments*	*Surveys*
Absolute	Cook	1	1 station
	Sakuma	1	1 "
	Faller-Hammond	1	9 "
Pendulum	Gulf	2	23 trips
	Cambridge	1	12 "
	IGC	2	4 "
	USCGS	2	2 "
	DO	1	1 "
	GSI	1	8 "
Gravimeter	LaCoste-Romberg	53	98 trips
	Worden	14	12 "
	Askania	2	6 "
	North American	2	5 "
	Western	3	2 "

3. – PRELIMINARY ADJUSTMENTS

3.1. Introduction

Individual adjustments with independently chosen procedures were produced by members of the Working Sub-Group. At the May, 1971 meeting held in Ottawa the various solutions described in detail in Apendices II to IV were presented. The differences in philosophy used in these preliminary adjustments were examined, the results were compared and the criteria chosen for the final adjustment.

The gravity values from all solutions agreed generally within ± 0.1 mGal in spite of different procedures used for selection, weighting and rejection of data. A few 0.1 to 0.2 mGal disagreements between the various solutions, mainly caused by excentre discrepancies, were resolved or the corresponding bases were deleted before the final adjustment.

Analyses of scale differences between pendulum and absolute measurements were carried out by four groups. The scale agreement of about 1:50,000 obtained from comparisons of gravimeter adjustments scaled by pendulum and absolute measurements respectively (App. II, III, IV) is consistent with the result of a separate analysis of pendulum scale (App. V).

3.2. Comparison of Individual Adjustments

Discussions at the May 1971 meeting of the Working Sub-Group in Ottawa were concerned mainly with the differences in the philosophy applied in various adjustments and the significance of some of the solution parameters.

All three groups performed several adjustments using various selection criteria for stations and measurements. For gravimeter measurements Uotila selected only LCR data while Whalen and McConnell & Gantar used all the available gravimeter data. The three groups performed adjustments with ties centred to primary bases. In addition, McConnell & Gantar adjusted all ties simultaneously. Details of the individual selection criteria are given in Appendices II, III, IV. A summary of the main characteristics of the individual adjustments is given in Table 3.1.

Table 3.1.

	Uotila (App. II)	*Whalen (App. III)*	*McConnell & Gantar (App. IV)*	*Remarks*
Selected Data Adjusted	X	X	X	4 to 600 unknowns; 7 to 11000 observations
All Data Adjusted			X	2 000 unknowns; 25 000 observations
Centred Data Adjusted	X	X	X	
Uncentred Data Adjusted	X partially		X	
1st order gravimeter scale unknown	X	X	X	
2nd order gravimeter scale unknown	X			
Scale unknown for *all* trips with the same gravimeter	X	X		
Scale unknown for individual trips with each gravimeter			X	

3.2.1. Comparison of Scale Factor Determination Criteria

All three groups performed adjustments with models using linear terms for gravimeter scale factors. In addition Uotila performed adjustments employing higher order scale factor terms. Both Uotila and Whalen solved for a single scale factor for each gravimeter (except for a few cases where repairs had obviously altered the scale factor) while Gantar and McConnell solved for a separate scale factor for each instrument-trip, grouping only those trips which had less than 10 measurements with the next trip occurring sequentially in time.

Adjustments using grouped instrument-trips generally indicated insignificant drift rates for gravimeters; solving for separate scale factors for each instrument-trip produced in several cases apparently significant drift rates.

Scale factors solved for each instrument-trip have been examined for possible variations as a function of time. While statistically significant changes in scale factor for the same gravimeter from one trip to the next were occasionally apparent (in some cases up to 15 parts in 10^5) there was no convincing evidence to suggest that they were systematic with time. Possibly these changes are a manifestation of the presence of slight non-linearities in the instruments. Thus, apparent changes in gravimeter scale factor may simply be due to the fact that all trips with the same instrument were not carried out over the same gravity range. The Working Sub-Group decided, for the final IGSN 71 adjustment, to solve for a single scale factor for all trips with the same instrument except where repairs had obviously altered the scale factor.

The Working Sub-Group agreed to use only a linear scale factor term in the final adjustment since the significance of higher order terms cannot be properly evaluated with the limited number of absolute measurements available.

3.2.2. Comparison of Gravity Values from Individual Solutions

Many comparisons of different solutions were carried out by plotting the gravity value differences against the gravity value of the station. In comparisons between solutions having first and second or higher order gravimeter scale factors some systematic dependence of the differences on the gravity value was apparent. Nevertheless, except for a few stations the gravity values agreed to within $\pm$ 0.1 mGal. One set of comparisons is shown in *Figures 3.1, 3.2 and 3.3.*

The solutions compared were those considered most reliable by the individuals concerned. These were :

(a) Uotila ; Solution 2A (Appendix II)

(b) McConnell & Gantar : BIGNET n° 4 (Appendix II)

(c) Whalen ; Adj. 4 (Appendix III).

o

o o

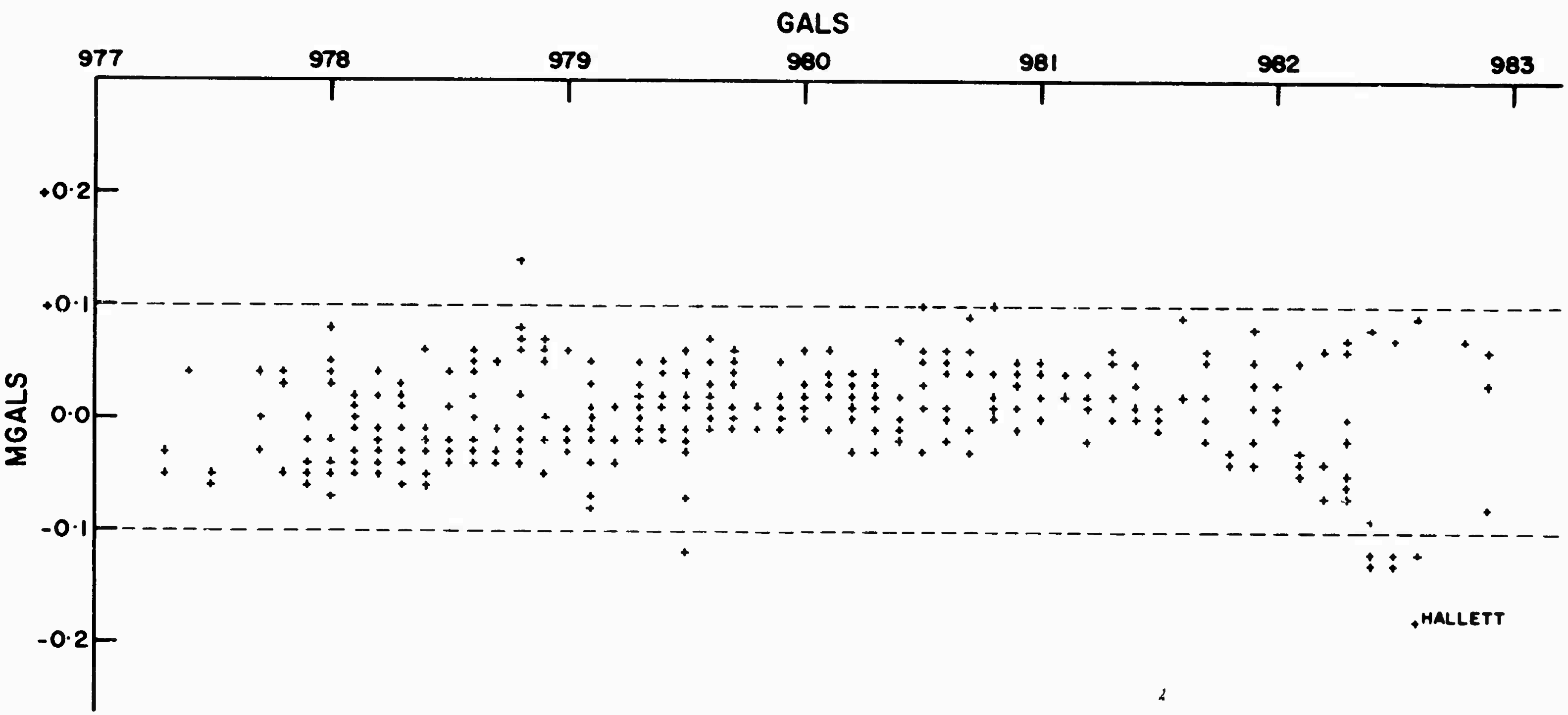


Fig. 3.1 : COMPARISON OF ADJUSTED GRAVITY VALUES
UOTILA MINUS McCONNELL & GANTAR

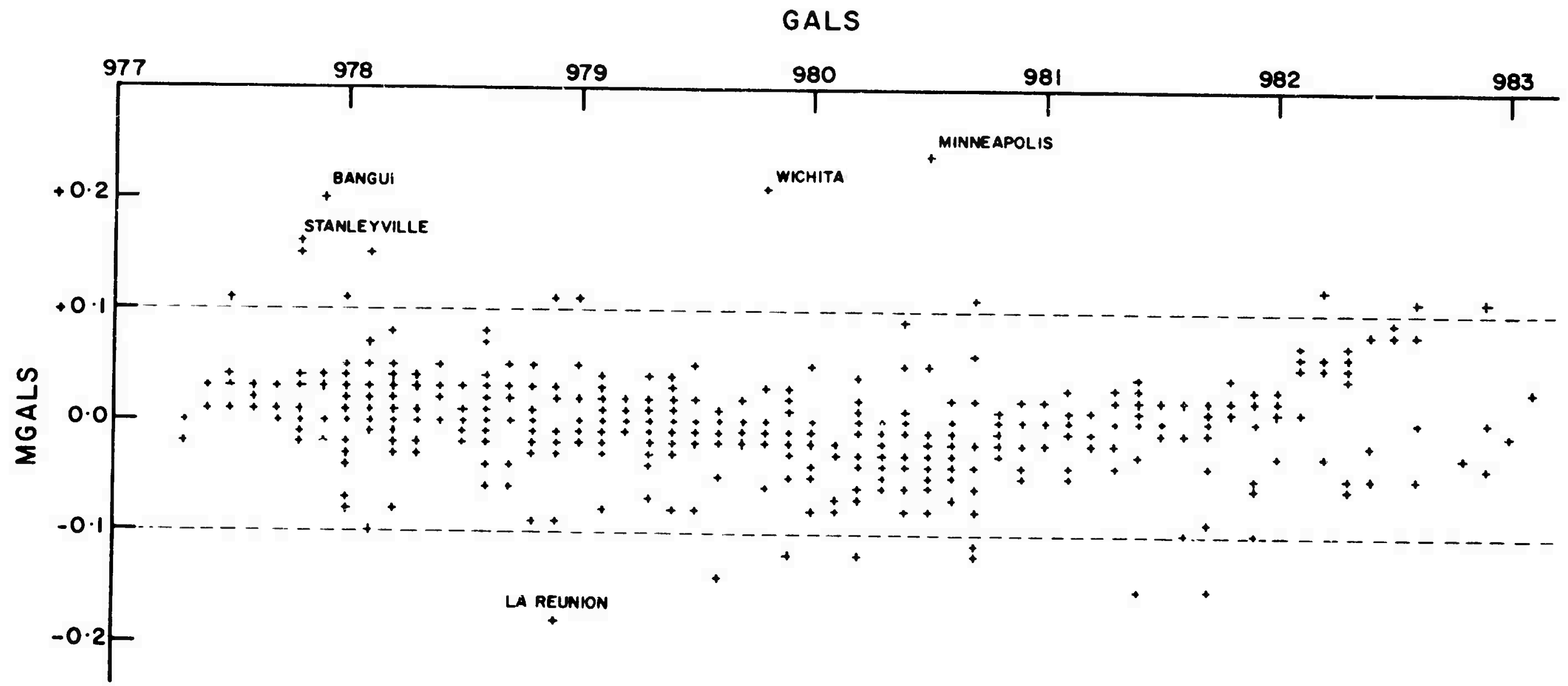


Fig. 3.2 : COMPARISON OF ADJUSTED GRAVITY VALUES
McCONNELL & GANTAR MINUS WHALEN

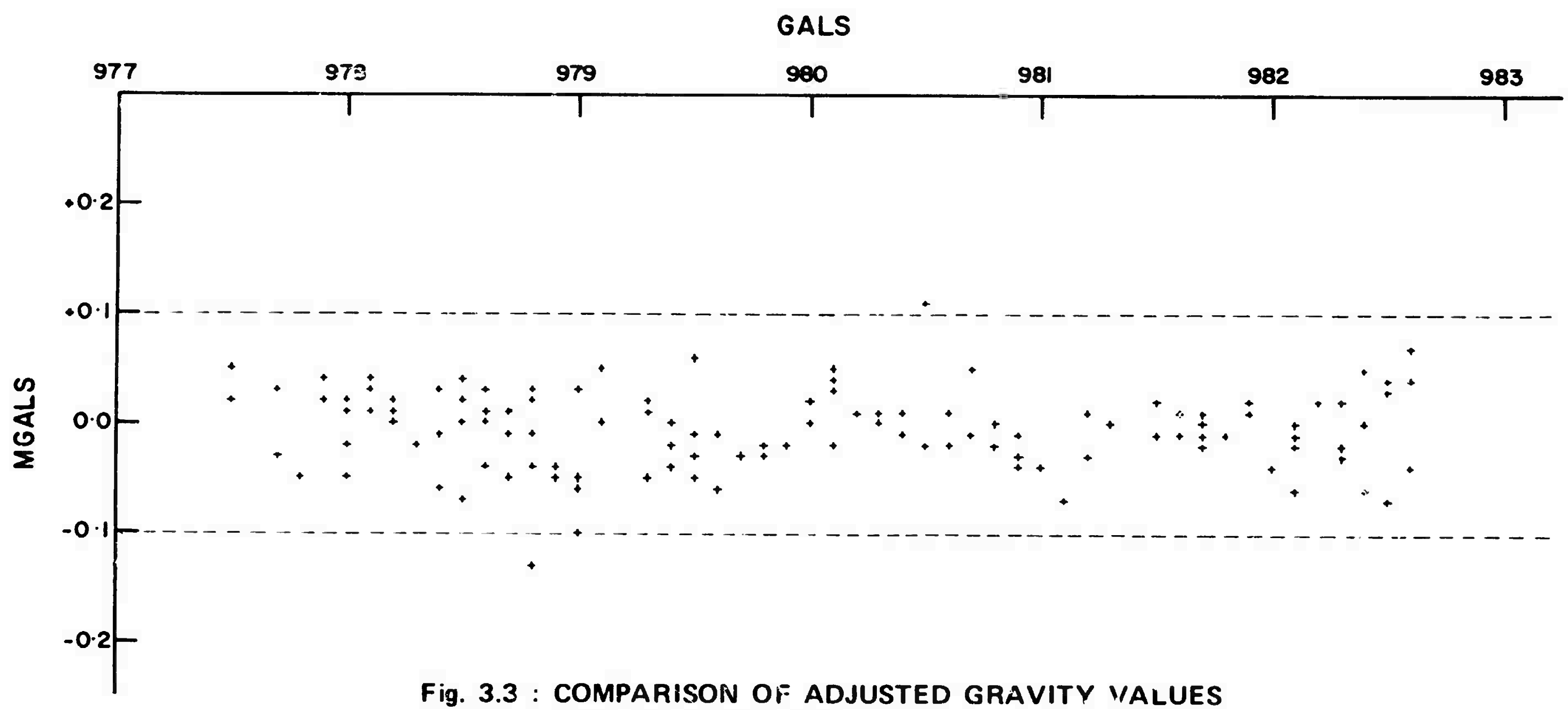


Fig. 3.3 : COMPARISON OF ADJUSTED GRAVITY VALUES
WHALEN MINUS UOTILA

4. – THE IGSN 71

4.1. Final Adjustment of the IGSN 71

The Working Sub-Group established the guide lines for the final adjustment. Observation equations were formed and rejections made using the Earth Physics Branch computer facilities and NETEDIT program (Appendix IV) in Ottawa. The solution of these observation equations was carried out using the computer facilities and matrix manipulation programs of the 1st Geodetic Survey Squadron in Cheyenne.

The problem of datum determination in the IGSN 71 has been resolved by including 10 recent absolute measurements in the adjustment in such a way that the net has a best fit to these measurements in the least squares sense. The scale of IGSN 71 was determined by the combined effect of the 10 absolute measurements and approximately 1200 pendulum measurements while the relative strength of the network was provided by some 12 000 long range LaCoste and Romberg gravimeter measurements (Figure 4.1). Approximately 11 700 excentre measurements make up the remainder of the network.

Measurements were weighted according to their error variances estimated for each instrument-trip from preliminary adjustments. A secondary weighting function, related to the time interval (ΔT) for the measurement, was used with the LaCoste and Romberg long range measurements (i.e. those between stations of differing IGB number). This weighting function (Figure 4.2) allowed for the observed increase in error variance with increasing ΔT.

Ties were rejected before the final adjustment if their errors, based on trial gravity values, exceeded 3σ. The trial gravity values and the value of σ were determined from preliminary Gauss-Seidel solutions of the same set of observation equations and, based upon comparisons with preliminary adjustments by other methods, were presumed to be accurate to a few one-hundredths of a mGal. Less than 3 % of the ties were rejected.

From the 24 974 observation equations a solution was obtained for 1854 gravity values, 96 gravimeter scale factors and 26 instrument (pendulum and gravimeter) drift rates. The gravity values and their standard errors are presented at the end of this report. For checking purposes, the gravity values from the final matrix inversion solution were compared with those from a Gauss-Seidel iterative solution carried out in Ottawa. Although the iterative solution differed from the matrix inversion solution in that it had no scale unknowns, the gravity values agreed in every case to better than 0.1 mGal.

4.2. IGSN 71 Gravity Values

The list of IGSN 71 gravity values is presented at the end of the report.

The system provides gravity values with standard errors less than 0.1 mGal over the gravity range of the earth.

According to Resolution n° 11 passed at the IUGG meeting, Moscow, 1971 a correction to the previously adopted Potsdam value has been computed.

The IGSN 71 gravity value for Potsdam A is 981260.19 ± 0.02 while the Potsdam reference value transferred to site A (Reicheneder, 1968) is 981274.20. The correction to the Potsdam reference value is therefore −14.0 mGal. It cannot be assumed that this correction applies to any point other than Potsdam since systems of gravity values based on Potsdam are unlikely to have the same scale as IGSN 71.

4.3. IGSN 71 Station Descriptions

Copies of IGSN 71 station descriptions may be obtained through the

International Gravity Bureau
11, Quai Saint-Bernard, Tour 14
75 - PARIS (Vème)

°
°   °

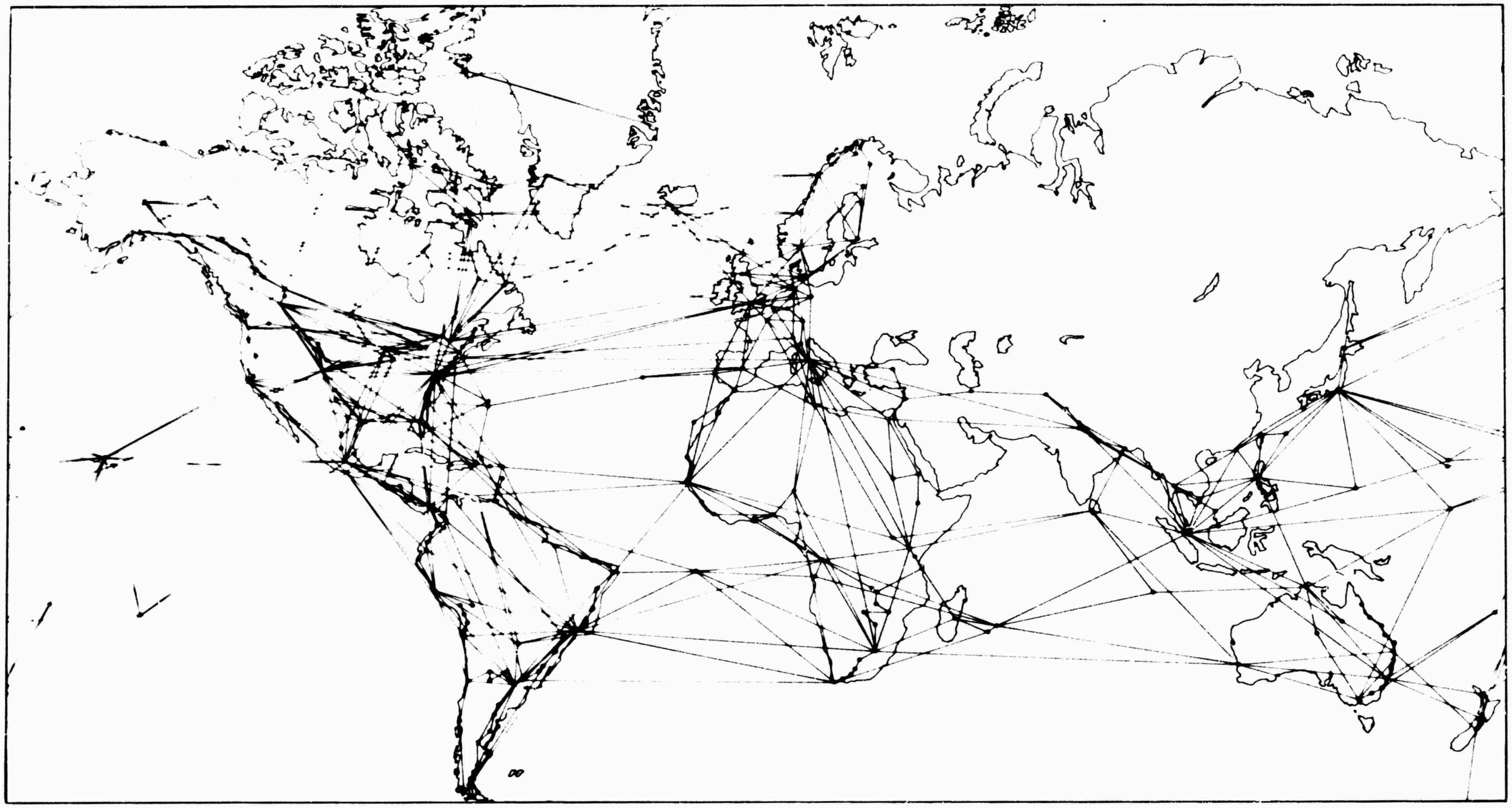


Fig. 4.1 : MAIN GRAVIMETER CONNECTIONS IN IGSN 71

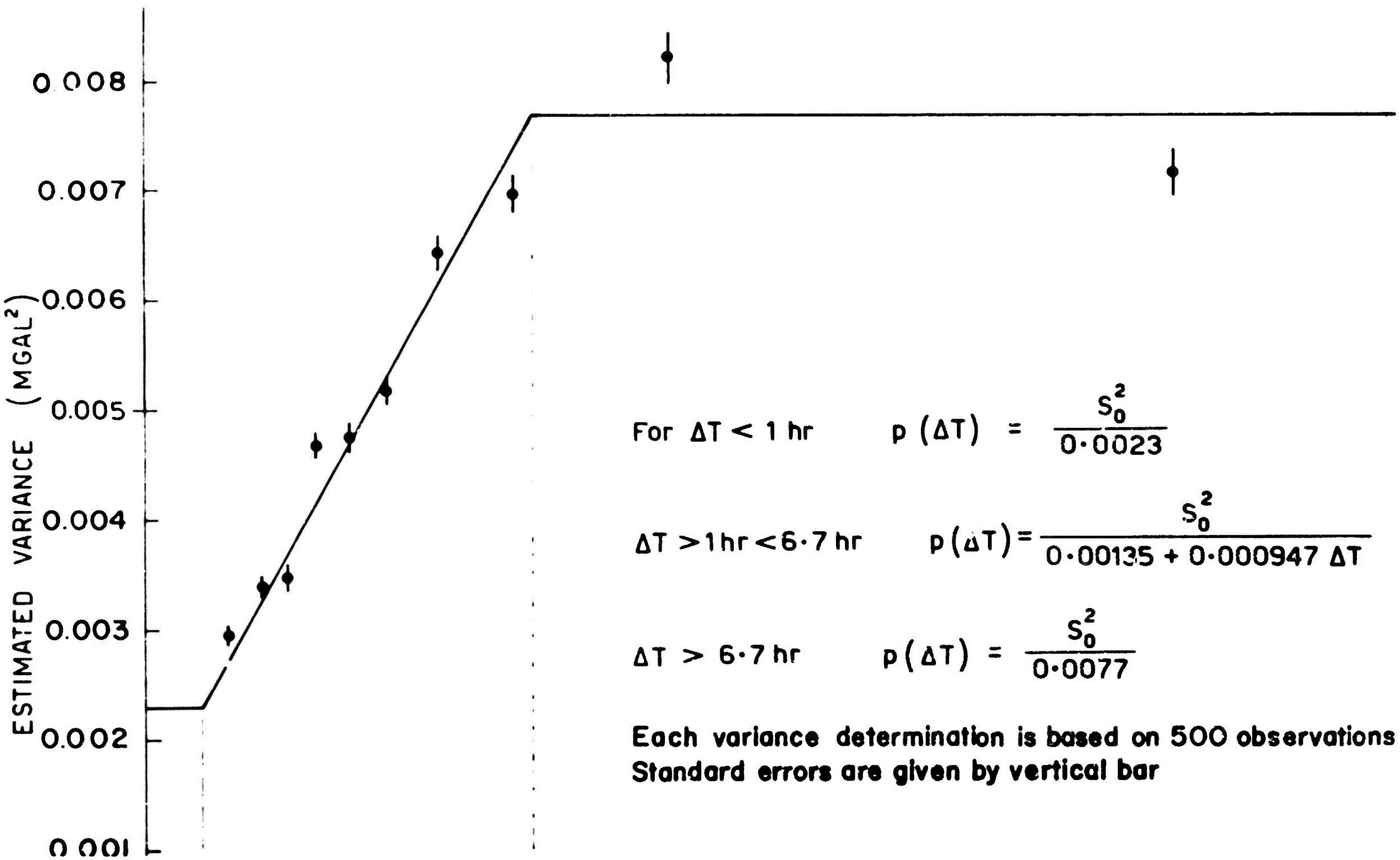


Fig. 4.2 : ΔT WEIGHTING FUNCTION FOR LCR OBSERVATIONS

5. – MAINTENANCE AND USE OF THE IGSN 71

The establishment of the IGSN 71 represents a major international effort and for this reason provision for maintenance has been made. The following resolution was passed at the XV General Assembly of the IUGG, Moscow, August, 1971 .

RESOLUTION N° 12

The International Association of Geodesy,

recommends that a *Permanent International Gravity Service,* coordinated with the *International Gravimetric Commission (IGC)* and the *International Gravimetric Bureau (IGB),* be formed with the following functions :

1. to provide for expansion of the IGSN 71 to include areas where no stations now exist or values are not available.

2. the maintenance and reobservation of stations, and the replacement of any which may be destroyed,

3. to maintain the files in a computer-processable format and to incorporate new measurements into the existing files (one complete set of the values and descriptions to be deposited at the IGB),

4. to promote improvements in instrumentation, including the development of transportable absolute gravity meters, and their applicability to the standardization problem,

5. to establish in cooperation with the appropriate scientific institutions a net of permanent stations at which the absolute measurement of gravity, periodically repeated with an accuracy of the order of a few microgals, could be used as a geodetic reference and, in conjunction with other advanced geodetic methods, to monitor slowly varying parameters of the earth,

6. to carry out computations necessary for incorporating new stations into the system,

7. to maintain contact with agencies active in the field of gravity measurements or using gravity data, to ensure that the IGSN 71 satisfies current needs,

8. to provide advice, when requested, to agencies using the IGSN 71 in local standardization problems.

Future improvements in gravity standards will require, in addition to several absolute measurements for resolving the gravimeter non-linearity problem, a large number of precise absolute measurements at strategic locations to determine the nature of time dependent gravity changes. Woollard (1969) has noted that we must recognize "that crustal parameters are not stable but change with time in response to changes in the environment (temperature, pressure and stress) associated with the upper mantle as well as in response to the effect of external factors (erosion, deposition, ice loading) on the crust, and tectonic displacement of both the crust and upper mantle through faulting and crustal spreading".

Global variations ("breathing"), variations in G and other effects must also be investigated. In this regard Levallois (1971) proposes 20 to 30 absolute stations at carefully selected locations.

It must be appreciated that the observations used for the determination of the IGSN 71 have been acquired over a period of more than 10 years. Therefore, in the event that changes in the gravity field have occurred, the IGSN 71 gravity values represent estimates of mean values over this period. From what is known about time dependent changes in gravity it is unlikely that these changes will significantly affect the IGSN 71 gravity values within the stated accuracy. However, in a few areas where large crustal movements are known or suspected, the corresponding gravity values should be used with some caution.

The IGSN 71 has been established to provide a uniform absolute reference system to which all relative gravity measurements may be referred. In general, local anomaly surveys will be referred to national or possibly continental sub-nets; the problem of ensuring optimum consistency of these sub-nets with the IGSN 71 has been examined. A suggested procedure for establishing new sub-nets or readjusting existing sub-nets is as follows :

(1) *Sub–nets incorporating several IGSN 71 stations*

The agency responsible for the establishment of a sub-net or the readjustment of an existing net should ensure that IGSN 71 stations are well tied to the local system. To achieve maximum consistency with the IGSN 71 system the adjustment of the sub-net should be made, not by fixing one or more IGSN 71 values but by weighting these values according to their error estimates; this is analogous to the procedure used for weighting the absolute measurements used to establish datum for the IGSN 71 itself. In this way, the sub-net is not forced to fit the IGSN 71 values exactly but optimum datum and scale consistency are ensured. This type of adjustment may, of course, produce slightly different values for the IGSN 71 stations involved, due to the higher internal consistency of the sub-net; these new values are appropriate for local use. If the IGSN 71 stations used are well distributed over the gravity range of the sub-net no separate calibration or evaluation of the gravimeters will be required since this can be achieved in the adjustment process itself.

(2) *Sub–nets incorporating few IGSN 71 stations*

To ensure optimum datum and scale consistency with the IGSN 71 the instruments used to establish the sub-net should first be calibrated and evaluated over several (at least 10) IGSN 71 stations encompassing a gravity range somewhat larger than the sub-net. The adjustment of the sub-net may then be carried out by treating as known quantities the scale factors obtained from the independent calibration. If only one IGSN 71 station is incorporated in the sub-net adjustment, the datum of the sub-net will of course have the same uncertainty as the station on which it is based.

6. – REFERENCES

A. BERROTH, 1949 : Das Fundamentalsystem der Schwere im Lichte neuer Reversionspendelmessungen. Bull. Géod. n. 12, pp. 183-204.

E. BORRASS, 1911 : Bericht über die relativen Messungen der Schwerkraft mit Pendelapparaten in der Zeit von 1808 bis 1909 und über ihre Darstellung im Potsdamer Schweresystem. Verhandlungen der 16 allgemeinen Konferenz der internationalen Erdmessung, 1909, 3 Teil : Spezialbericht über die relativen Schweremessungen.

B.C. BROWNE, 1962a : Memorandum on the technique of measuring relative gravity values on land by means of pendulums. Bull. Geod. 64, pp. 145-168.

B.C. BROWNE, 1962b : African trip with the Cambridge pendulums in 1958. Unpublished Report.

B.C. BROWNE, T. HONKASALO, 1969 : Cambridge Pendulum Measurements of Gravity Differences on the West Pacific Calibration Base. Unpublished Report.

Bureau Gravim. Internat., 1963 : Recording of Gravity Data on Punched Cards. Bull. d'Information B.G.I., n. 5, Paris.

H.J. BUTEAU, C.T. WHALEN, 1965 : The East Coast Calibration Line (ECCL). Presented to 5th Meeting AGU, Dallas, Texas, September 1965.

J.S. CLARK, 1939 : An absolute determination of the acceleration due to gravity. Philos. Trans. Roy. Soc. London, A. 238, pp. 65-123.

A.H. COOK, 1965a : The Absolute Determination of the Acceleration due to Gravity. Metrologia, I, 3.

A. H. COOK, 1965b : A new Absolute Determination of the Acceleration due to Gravity at the N P L. Ibidem, 1, 4, p. 184.

A. H. COOK, 1967 : A New Absolute Determination of the Acceleration due to Gravity at the National Physical Laboratory, England, Phil. Trans. Roy. Soc. London, Ser. A, 261, pp. 211-252.

A.H. COOK, J.A. HAMMOND, 1969 : The Acceleration due to Gravity at the National Physical Laboratory. Metrologia 5, 4, pp. 141-142.

S. CORON, 1956 : Réseau gravimétrique international de premier ordre (système de Potsdam). B.G.I., Paris.

S. CORON, 1968 : Première note récapitulative sur les grandes liaisons gravimétriques françaises. (unp. manuscript), B.G.I., Paris.

S. CORON, F. MONNET, 1959 : Réseau gravimétrique international de premier ordre. Système de Potsdam, Publ. B.G.I.

Data Reduction Division, 1381 st GSS, 1963 : Environmental Testing of Gravity Meters. (unp. manuscript), Orlando AFB, Florida.

H.L. DRYDEN, 1942 : A re-examination of the Potsdam absolute determination of gravity. J. Res. Nat. Bur., Washington, 29, pp. 303-327.

F. DUCLAUX, J. MARTIN, 1952 : Résultats de la première campagne gravimétrique effectuée en Afrique de Mars à Juin 1952. ([illegible]) O.R.S.T.O.M., Paris.

F. DUCLAUX, J. MARTIN, C. BLOT, R. REMIOT, 1954 : Etablissement d'un Réseau Général de Stations Gravimétriques en Afrique, à Madagascar, à La Réunion et à l'Ile Maurice. (unp.) O.R.S.T.O.M., Paris.

C. ELSTNER, R. SCHWARZBERG, 1965 : Relative Pendelmessungen zwischen Potsdam und Rome. Deutsche Akad. Wiss. Arbeiten aus dem. Geod. Inst. Potsdam No. 11.

J.E. FALLER, 1963 : An Absolute Interferometric Determination of the Acceleration of Gravity. Thesis, Princeton University.

J.E. FALLER, 1965a : An Absolute Interferometric Determination of the Acceleration of Gravity. Bull. Geod. n. 77, pp. 203-204.

J.E. FALLER, 1965b · Results of an Absolute Determination of the Acceleration of Gravity. J. Geoph. Res. 70, 16, pp. 4035-4038.

J.E. FALLER, J.A. HAMMOND, 1970 : A Laser - Interferometer System for the Absolute Determination of the Acceleration of Gravity. AFCRL-70-0163 Final Report.

C. GANTAR, 1959 : Confronto diretto fra le basi gravimetriche di taratura (convenzionale) italiana e francese. Boll. Geof. teor. ed appl., Trieste, I, 2, pp. 121-131.

C. GANTAR, C. MORELLI, 1959 : Revisione critica delle misure effettuate con gravimetri Worden dal 1951 al 1959. Ibidem, I, 3, pp. 181-220.

C. GANTAR, C. MORELLI, 1962 : Measurements with gravity-meters along the northern part of the European Calibration Line, Bad Harzburg-Bodo. Ibidem, IV, 15, pp. 183-228.

C. GANTAR, C. MORELLI, M.T. CARROZZO, 1969 : Adjustment of Pendulum Gravity Measurements for the Calibration of the First Order World Gravity Net. Unp. OGST Scient. Rep. No 2 to AFCRL, Bedford, Mass. U.S.A.

G.D. GARLAND, 1953 : Gravity Measurements in North America with the Cambridge Pendulum Apparatus. Proc. Roy. Soc., A., Vol. 219, pp. 215-233.

G.D. GARLAND, 1955 : Gravity Measurements in North America with the Cambridge Pendulum Apparatus II. Ibidem Vol. 233, pp. 203-213.

G.D. GARLAND, A.H. COOK, 1955 : A Determination of the Differences in Gravity between the National Physical Laboratory, Teddington, the Dominion Observatory, Ottawa and the National Bureau of Standards, Washington. Proc. Roy. Soc., Vol. 1, N. 16, pp. 445-458.

D.I. GOUGH, 1958 : A new determination of the difference in gravity between the N.P.L. Teddington and the South African Fundamental and Secondary Stations. Geoph. Journ., V. 3, No. 20, pp. 298-307.

A.C. HAMILTON, 1963 : A Comparison of Gravity Standards in Europe and the Americas. Unp. paper presented to XIII I.U.G.G. Gen. Ass., Berkeley U.S.A.

A.C. HAMILTON, B.G. BRULE, 1967 : Vibration - induced drift in LaCoste and Romberg geodetic gravimeters. J.G.R., 72, 8, pp. 2187-2197.

J.A. HAMMOND, J.E. FALLER, 1971 : Results of Absolute Gravity Determinations at a Number of Different of Sites, J.G.R., 76, 32, pp. 7850-7854.

Y. HARADA, 1967 : Gravity observations along the Western Pacific Calibration Line during the period from 1965 to 1967 with G.S.I. pendulums. Unp. Report, Annexe 2.4.5 of the I.A.G., S.S.G. 5 Report to the XIV Gen. Ass. of the I.U.G.G., Zürich.

Y. HARADA, S. KAKINUMA, I. MURATA, 1963 : Pendulum determination of the gravity differences between Tokyo, Mowbray, and Syowa Base. The Nat. Sci. Museum, Tokyo, Antarctic Record No. 17, pp. 1465-1480.

Y. HARADA, H. SUZUKI, S. OHASHI, 1959 : Report on the Gravity Measurements by the Japanese Antarctic Research Expedition (I.A.R.E.) Antarctic Record, No. 6.

Y. HARADA, H. SUZUKI, S. OHASHI, S. KAKINUMA, 1960 : Determination of the difference in gravity between Chiba, Singapore, Cape Town and Syowa station in Antarctica. Bull. Geogr. Surv. Inst. VI, 2-3, pp. 135-156.

P.R. HEYL, G.S. COOK, 1936 : The value of gravity at Washington. J. Res. Nat. Bur. Stand., Washington 17, pp. 806-839.

R.A. HIRVONEN, 1948 : On the establishment of the values of gravity for the national reference stations. A.n. Acad. Sci. Fennicae, Helsinki, A. III, Geol. Geogr. 17.

T. HONKASALO, 1960 : Tying of the Gravity Base Station Helsinki to Potsdam and to the European Calibration Line. Unp. manuscript presented to XII I.U.G.G. Gen. Ass., Helsinki.

T. HONKASALO, 1964a : On the tidal gravity correction. Boll. Geof. teor. ed appl. VI, 21, pp. 34-36. Presented at I.G.C. Meeting in Paris 1959.

T. HONKASALO, 1964b : Unpublished report for Special Study Group N° 5 of the I.U.G.G. on Gravity Measurements in the F.O.W.G.N. with Cambridge pendulum apparatus, carried out by the Finnish Geodetic Institute.

T. HONKASALO, 1968 : Recomputation of the temperature correction for previous Cambridge pendulum measurements. Unpublished report distributed among the members of Working Sub-Group.

T. HONKASALO, J.E. JACKSON, D.I. GOUGH, B.C. BROWNE, 1967 : Report of the S.S.G. 4.05 of the I.A.G. on the gravity measurements in the F.O.W.G.N. with Cambridge Pendulum Apparatus in 1963-64. Annexe 2.4.2b of the I.A.G., S.S.G. 5 Report to the XIV Gen. Ass. of the I.U.G.G., Zürich.

E. INOUE, 1961 : A new G.S.I. pendulum apparatus. Bull. of G.S.I., VI, 4, pp. 167-200.

E. INOUE, T. SETO, 1961 : Pendulum determination of the gravity differences between Tokyo and Melbourne. Ibidem Vol. VI, part. 4, pp. 201-211.

J.E. JACKSON, 1959 : Observations with the Cambridge pendulum apparatus in North, Central and South America in 1958. Geoph. Journal, 2, 4, pp. 337-347.

J.E. JACKSON, 1960 : Pendulum observations at Teddington, Singapore, Darwin and Melbourne in 1959, Ibidem, 3, 1, pp. 78-82.

J.E. JACKSON, 1961 : The Cambridge pendulum apparatus. The Earth Today, R.A.S., spec. issue of Geoph. Journ., London, pp. 375-388.

G. JELSTRUP, 1957 : Observations on the Gravimetric Calibration Base Hammerfest - Munich with the Cambridge Pendulum Apparatus. Norg. Geogr. Oppmaling, Geod. publ. No. 7, Oslo.

M. KNEISSL, K. MARZAHN, 1963 : The adjustment 1962 of the European Calibration System. Bull. Geod., 69, pp. 217-229.

F. KÜHNEN, P. FURTWÄNGLER, 1906 : Bestimmung der Absoluten Grosse der Schwerkraft zu Potsdam. Veroffentlichung des K. Preuszischen Geod. Inst. N.F. n. 7.

J. J. LEVALLOIS, 1971 : Quelques conséquences géophysiques des nouvelles méthodes de haute précision de mesures absolues de g. Bull. Géod. 99, pp. 111-112.

I. M. LONGMAN, 1959 : Formulas for computing the tidal acceleration due to the moon and the sun. J. Geoph. Res., 64, pp. 2351-2355.

J. MARTIN, 1955 : Etalonnage des gravimètres sur les bases pendulaires européennes. Exp. Pol. Franc., Paris (2ème édition).

J. MARTIN, P. STAHL, F. MUNCH, A. JOSET, 1954 : Expéditions Polaires Françaises - Groenland 1948-52. Gravimétrie, lère Partie : Valeurs de g. Exp. Pol. Franc., R.S., Paris.

C. MAZZON, 1957 : L'apparato tripendolare della Commissione Geodetica Italiana : Studio teorico-sperimentale. Publ. dell'Ist. di Geod., Topogr. e Fotogr. Politecn. di Milano n. 97.

C. MAZZON, 1961a : Mesures pendulaires exécutées sur la L.T.E. de Hammerfest à Catania. Bull. Géod. 60, pp. 167-176.

C. MAZZON, 1961b : Determinazioni pendolari eseguite sulla parte settentrionale della linea di taratura europea dei gravimetri. Pubbl. CGI, Mem. n. 14.

C. MAZZON, 1965 : Il nuovo registratore fotografico diretto dell'apparato tripendolare n. 2 della Commissione Geodetica Italiana. Pubbl. Ist. Geodesia Polit., Milano, n. 165.

C. MAZZON, 1967 : Report about the pendular expeditions carried out by means of the Italian three-pendulum apparatus C.G.I., n. 1 and n. 3, in Europe and Africa in 1963-1964. Unpublished Report Annexe 2.4. 3b of the I.A.G., S.S.G. 5 Report to the XIV Gen. Ass.of the I.U.G.G. Zürich.

C. MAZZON, L. PIERI, 1959 : Primo contributo alle misure pendolari sulla base europea di taratura dei gravimetri. Pubbl. CGI, Mem. n. 12.

C. MORELLI, 1946a : Per un sistema di riferimento "internazionale" delle misure di gravità. Nota preliminare. Geof. pura ed appl., VIII, pp. 81-93.

C. MORELLI, 1946b : Compensazione della rete internazionale delle stazioni di riferimento per le misure di gravità relativa. Boll. Soc. Adr. Sc. Nat., Vol. XLI.

C. MORELLI, 1959 : Special Study Group n. 5. General Report. Bull. Geod. 51, pp. 7-43.

C. MORELLI, 1963 : The First Order and Absolute World Gravity Nets. Boll. Geof. teor. ed appl., Trieste, V, 19, pp. 195-216.

C. MORELLI, 1967 : Final Results of Cambridge and CGI Pendulum Measurements. Unp. OGST Scient. Rep. No. 1 to AFCRL, Bedford, Mass. U.S.A.

C. MORELLI, C. GANTAR, L. ZAMPIERI, S. CORON, 1965 : Catalogue of Pendulum Station and Excenters, for the First Order World Gravity Net, and principal Related Stations. IAG-S.S.G.5, B.G.I., distrib. at the IGC Meeting, September 1965, Paris.

K. MUTO, 1953 : A G.S.I. pendulum apparatus for gravity measurements. Proc. Jap. Acad. 29, N° 81, pp. 439-445.

T. OKUDA, E. INOUE, H. SUZUKI, 1956 : Determination of the difference in gravity values at the C&GS, the N.B.S. Washington D.C. and the G.S.I. Bull. Geogr. Survey Inst., Vol. V, Part 1, pp. 1-12.

H. PRESTON-THOMAS, L.G. THURNBULL, E. GREEN, T.M. FAUPHINE, S.N. KALRA, 1960 : An absolute measurement of the acceleration due to gravity at Ottawa. Can. Journ. Phys., 38, 6, 824.

K. REICHENEDER, 1968 : The local gravity conditions in the Geodetic Institute Potsdam. Boll. Geof. teor. ed appl., X, 40, pp. 332-340.

D.A. RICE, 1958 : Gravity control measurements in North America. USC & GS publ. 63-1.

A. SAKUMA, 1966 : Report in Bull. Inform. Bur. Gravimetrique Internationale, n. 14, pp. I-6, I-7.

A. SAKUMA, 1969 : Report in Bull. Inform. Bur. Gravimetrique Internationale, n. 24, pp. I-34.

A. SAKUMA, 1971 : Recent Development in the Absolute Measurements of Gravity, Proceeding of the International Conference on Precision Measurement and Fundamental Constants, edited by D.N. Laugenberg and B.N. Taylor. NBS Spec. Publ. 343, 1971.

L. SOLAINI, C. MORELLI, C. GANTAR, G. INGHILLERI, 1961 : Misure con gravimetri lungo la linea di taratura europea tra Bad Harzburg e l'Osservatorio Etneo. Pubbl. Comm. Geod. Ital., III S., mem. no. 15.

C.H. SWICK, 1942 : Pendulum gravity measurements and isostatic reductions. USC & GS spec. publ. 232.

B. SZABO, 1963 : World Calibration Standard, First Order Gravity Net and Absolute Gravity System. Boll. Geof. teor. ed appl., Trieste, V, 19, pp. 251-259.

B. SZABO, 1966 : The Status of the World Gravity Standardization and First-Order Net. Geophys. Mon., Ser. n. 9, Am. Geoph. Un.

B. SZABO, 1969 : A Review of the First Order World Gravity Net. Presented to XI Pan. Am. Consult. on Cartography, Washington, publ. by A.F. Cambridge Res. Lab., Bedford, Mass.

D.R. TATE, 1968 : Acceleration Due to Gravity at the National Bureau of Standards. J. Res. NBS, Vol. 72 C, No. 1, pp. 1-20.

D.R. TATE, 1969 : Gravity Measurements and the Standards Laboratory, NBS (U.S.), Tech. Note 491.

W. TORGE, 1966 : Untersuchungen zur Genauigkeit moderner Langstreckengravimetermessungen dargestellt am Beispiel des mit Askania-Gravimetern GS12 beobachteten euroafrikanischen Schwerenetzes. Wiss. Arb. Geod., Techn. Hochschule, Hanover, No. 29.

U.A. UOTILA, 1964 : Adjustment of a World-Wide Gravity Base Station Network. Ann. Acad. Sci. Fennicae, Helsinki, A III, 73.

H.D. VALLIANT, 1969a : The Canadian pendulum apparatus, design and operation. Trans. Inst. Elect. Electron. Engrs. GE 5.

H.D. VALLIANT, 1969b : Gravity Measurements on the North American Calibration Line with the Canadian Pendulum Apparatus. The Geophysical Journal, V. 17, No. 5, pp. 489-505.

C.T. WHALEN, 1965a : Extension of the American Calibration Line from Mexico City, to Ushuaia. Unpublished Report. 1381st GSS, Orlando AFB, Florida.

C.T. WHALEN, 1965b : The Euro-African Calibration Line (EACL). Ibidem.

C. T. WHALEN, 1966a : On the precision of Dial Factor Tables for LaCoste and Romberg gravimeters. Presented to 47th AGU Meeting, Washington D.U., April 1966.

C. T. WHALEN, 1966b : The West Pacific Calibration Line Survey, 1964-65. Unpublished Report 1381st GSS, Francis E. Warren AFB, Wyoming.

C.T. WHALEN, 1966c : The Euro-African Secondary Calibration Line Survey, 1965. Ibidem.

C.T. WHALEN, H.C. HARRIS, 1966 : U.S. National Gravity Base Net, Phase I. Ibidem.

C.T. WHALEN, 1967a : The American Secondary Calibration Line. Ibidem.

C.T. WHALEN, 1967b : Preliminary Results, U.S. National Gravity Base Net, Phase II. Ibidem.

G.P. WOOLLARD, 1963 : An Evaluation of the Potsdam Datum. Hawaii Inst. of Geophys., Univ. of Hawaii, Sci. Rep. N° 1.

G.P. WOOLLARD, 1965 : Results for Gulf pendulum measurements in 1964 on the American Gravity Standardization Range and in 1963 on the European - African Standardization Range. Unpublished Report, distributed among the members of Sub-Group.

G.P. WOOLLARD, 1969 : Standardization of Gravity Measurements. From : the Earth's Crust and Upper Mantle, Geoph. Monog. No. 13, AGU, pp. 283-293.

G.P. WOOLLARD, R.L. LONGFIELD, 1968 : Gulf pendulum and LaCoste-Romberg gravimeter results under the International Gravity Standardization Program (parts I-III). Unpublished Report, distributed among the members of Sub-Group.

G.P. WOOLLARD, R.L. LONGFIELD, B. CARLSON, 1962 : Final Report on 1961-62 Gravity Standardization Studies. W.H.O.I. Ref. 62-63, unpublished manuscript.

G.P. WOOLLARD, J.C. ROSE, 1963 : International Gravity Measurements. S.E.G. Monography, Univ. of Wisconsin, Geoph. and Polar Res. Center.

LISTING OF IGSN 71
GRAVITY VALUES

EXPLANATION OF COLUMN HEADINGS

- IGB Number - The first three digits of the IGB number are computed from the geographical coordinates of the station using the following formulae :

quadrant I		$36 + 36\ (\Phi_x) - \lambda_x$
quadrant II		$1 + 36\ (\Phi_x) + \lambda_x$
quadrant III		$325 + 36\ (\Phi_x) + \lambda_x$
quadrant IV		$360 + 36\ (\Phi_x) - \lambda_x$

where	quadrant I	is	0° N	to	90° N Lat.
			0° E	to	180° E Long.
	quadrant II	is	0° N	to	90° N Lat.
			0° W	to	180° W Long.
	quadrant III	is	0° S	to	90° S Lat.
			0° W	to	180° W Long.
	quadrant IV	is	0° S	to	90° S Lat.
			0° E	to	180° E Long.

and Φ_x is the tens of degrees of latitude

λ_x is the tens of degrees of longitude.

The last two digits of the IGB number are simply the units of latitude and longitude degrees.

For example, since Tokyo A is located at Lat. 35°42.6' N, Long. 139°46.0' E the first three digits of the IGB number are given by :

$$36 + 36\ (3) - 13 = 131$$

and the complete number is therefore 13159. Note that the first three digits of the IGB number define 10° squares. These are shown on the accompanying map. For the purpose of the IGSN 71, excentre stations have been assigned the same IGB code as the primary even though they may, in a few instances, lie outside the 10° square of the primary.

Name - In general the name of the primary station is used for the corresponding excentre stations. In Europe, however, stations with the same IGB number are not always considered to be excentres. In these cases the actual station name has been used.

Gravity Value - These are expressed in mGal.

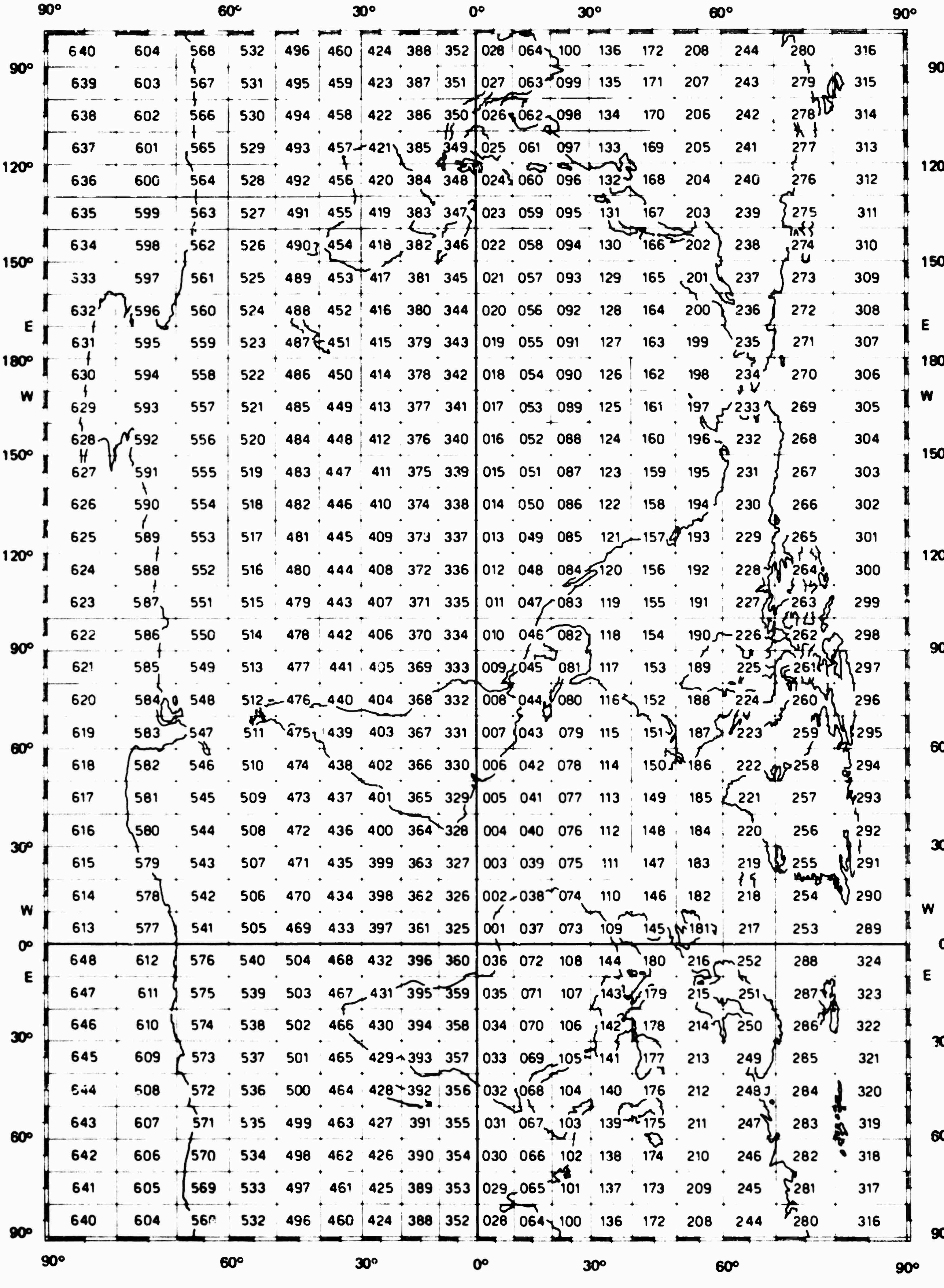
Std. Error - These are the error estimates in mGal obtained from the inverse matrix.

Times Tied

Int. - number of connections to stations with the same IGB number.

Ext. - number of connections to stations with differing IGB numbers.

Preceding page blank


90° 60° 30° 0° 30° 60° 90°
640 604 568 532 496 460 424 388 352 028 064 100 136 172 208 244 280 316
639 603 567 531 495 459 423 387 351 027 063 099 135 171 207 243 279 315
638 602 566 530 494 458 422 386 350 026 062 098 134 170 206 242 278 314
637 601 565 529 493 457 421 385 349 025 061 097 133 169 205 241 277 313
636 600 564 528 492 456 420 384 348 024 060 096 132 168 204 240 276 312
635 599 563 527 491 455 419 383 347 023 059 095 131 167 203 239 275 311
634 598 562 526 490 454 418 382 346 022 058 094 130 166 202 238 274 310
633 597 561 525 489 453 417 381 345 021 057 093 129 165 201 237 273 309
632 596 560 524 488 452 416 380 344 020 056 092 128 164 200 236 272 308
631 595 559 523 487 451 415 379 343 019 055 091 127 163 199 235 271 307
630 594 558 522 486 450 414 378 342 018 054 090 126 162 198 234 270 306
629 593 557 521 485 449 413 377 341 017 053 089 125 161 197 233 269 305
628 592 556 520 484 448 412 376 340 016 052 088 124 160 196 232 268 304
627 591 555 519 483 447 411 375 339 015 051 087 123 159 195 231 267 303
626 590 554 518 482 446 410 374 338 014 050 086 122 158 194 230 266 302
625 589 553 517 481 445 409 373 337 013 049 085 121 157 193 229 265 301
624 588 552 516 480 444 408 372 336 012 048 084 120 156 192 228 264 300
623 587 551 515 479 443 407 371 335 011 047 083 119 155 191 227 263 299
622 586 550 514 478 442 406 370 334 010 046 082 118 154 190 226 262 298
621 585 549 513 477 441 405 369 333 009 045 081 117 153 189 225 261 297
620 584 548 512 476 440 404 368 332 008 044 080 116 152 188 224 260 296
619 583 547 511 475 439 403 367 331 007 043 079 115 151 187 223 259 295
618 582 546 510 474 438 402 366 330 006 042 078 114 150 186 222 258 294
617 581 545 509 473 437 401 365 329 005 041 077 113 149 185 221 257 293
616 580 544 508 472 436 400 364 328 004 040 076 112 148 184 220 256 292
615 579 543 507 471 435 399 363 327 003 039 075 111 147 183 219 255 291
614 578 542 506 470 434 398 362 326 002 038 074 110 146 182 218 254 290
613 577 541 505 469 433 397 361 325 001 037 073 109 145 181 217 253 289
648 612 576 540 504 468 432 396 360 036 072 108 144 180 216 252 288 324
647 611 575 539 503 467 431 395 359 035 071 107 143 179 215 251 287 323
646 610 574 538 502 466 430 394 358 034 070 106 142 178 214 250 286 322
645 609 573 537 501 465 429 393 357 033 069 105 141 177 213 249 285 321
644 608 572 536 500 464 428 392 356 032 068 104 140 176 212 248 284 320
643 607 571 535 499 463 427 391 355 031 067 103 139 175 211 247 283 319
642 606 570 534 498 462 426 390 354 030 066 102 138 174 210 246 282 318
641 605 569 533 497 461 425 389 353 029 065 101 137 173 209 245 281 317
640 604 568 532 496 460 424 388 352 028 064 100 136 172 208 244 280 316
90° 120° 150° E 180° W 150° 120° 90° 60° 30° W 0° E 30° 60° 90°
90° 60° 30° 0° 30° 60° 90°

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
00150 A	ACCRA	978 091.41	0.035	16	4
00150 B	ACCRA	978 105.36	0.033	8	0
00150 J	ACCRA	978 100.52	0.033	16	2
00150 K	ACCRA	978 100.46	0.031	16	8
00150 L	ACCRA	978 081.91	0.038	16	0
00150 M	ACCRA	978 015.68	0.040	8	0
00154 J	ABIDJAN	978 060.78	0.068	4	3
00154 K	ABIDJAN	978 061.15	0.070	4	0
00154 L	ABIDJAN	978 057.14	0.056	0	4
00174 J	BOUAKE	978 054.32	0.060	0	4
00260 B	MONROVIA	978 145.06	0.032	16	0
00260 C	MONROVIA	978 142.79	0.035	8	0
00260 J	MONROVIA	978 093.44	0.032	8	0
00260 K	MONROVIA	978 093.43	0.030	16	16
00260 L	MONROVIA	978 094.14	0.070	0	2
00283 J	FREETOWN	978 183.67	0.069	0	2
00293 B	CONAKRY	978 222.91	0.031	8	0
00293 J	CONAKRY	978 210.94	0.029	8	16
00293 K	CONAKRY	978 210.62	0.052	0	5
00655 J	PARAMARIBO	978 033.50	0.026	0	16
00668 B	GEORGETOWN	978 107.45	0.030	7	0
00668 J	GEORGETOWN	978 075.70	0.027	14	22
00668 K	GEORGETOWN	978 075.55	0.030	11	2
00668 L	GEORGETOWN	978 102.48	0.035	4	0
00793 J	MATURIN	977 996.31	0.041	2	2
00793 K	MATURIN	977 996.19	0.043	2	2
00826 K	POPAYAN	977 584.49	0.026	7	21
00826 L	POPAYAN	977 584.47	0.028	7	7
00836 A	CALI	977 845.58	0.029	5	0
00836 K	CALI	977 804.89	0.025	5	42
00844 A	BOGOTA	977 390.11	0.026	19	25
00844 B	BOGOTA	977 390.07	0.032	4	0
00844 C	BOGOTA	977 390.14	0.027	2	0
00844 J	BOGOTA	977 386.91	0.031	5	0
00844 K	BOGOTA	977 380.59	0.026	14	28

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
00865 K	MEDELLIN	977 740.64	0.024	7	21
00865 L	MEDELLIN	977 741.19	0.026	7	6
00889 A	PANAMA	978 226.70	0.019	111	34
00889 J	PANAMA	978 251.44	0.019	48	55
00889 L	PANAMA	978 216.72	0.023	7	2
00889 M	PANAMA	978 216.74	0.019	41	67
00889 O	PANAMA	978 224.00	0.026	5	0
00889 R	PANAMA	978 222.54	0.029	3	2
00889 S	PANAMA	978 227.72	0.020	24	10
00889 T	PANAMA	978 251.34	0.022	9	6
00899 J	CRISTOBAL	978 238.56	0.034	0	4
00994 K	SAN JOSE	977 964.36	0.023	4	36
00994 L	SAN JOSE	977 963.59	0.026	4	4
02087 J	KWAJALEIN	978 346.43	0.050	0	7
02613 A	SINGAPORE	978 066.68	0.025	95	49
02613 B	SINGAPORE	978 066.04	0.026	50	0
02613 C	SINGAPORE	978 066.02	0.030	7	0
02613 D	SINGAPORE	978 066.25	0.031	6	0
02613 E	SINGAPORE	978 065.21	0.045	2	0
02613 F	SINGAPORE	978 061.86	0.028	9	0
02613 J	SINGAPORE	978 066.81	0.027	28	0
02613 K	SINGAPORE	978 063.95	0.027	16	0
02613 L	SINGAPORE	978 065.61	0.026	29	11
02613 M	SINGAPORE	978 064.95	0.026	19	0
02613 O	SINGAPORE	978 065.42	0.025	59	21
02613 P	SINGAPORE	978 061.29	0.026	32	24
02613 Q	SINGAPORE	978 063.71	0.031	4	3
02613 S	SINGAPORE	978 063.80	0.030	4	4
02622 J	MALACCA	978 057.88	0.042	0	4
02631 B	KUALA LUMPUR	978 034.41	0.031	8	0
02631 J	KUALA LUMPUR	978 032.41	0.028	8	20
02650 J	PENANG	978 078.13	0.030	0	16
02670 J	SONGKHLA	978 121.13	0.031	8	20
02670 K	SONGKHLA	978 130.79	0.033	8	0
02969 B	COLOMBO	978 117.24	0.054	18	0
02969 C	COLOMBO	978 124.54	0.060	2	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
02969 D	COLOMBO	978 123.11	0.056	4	0
02969 J	COLOMBO	978 116.90	0.053	13	11
02969 K	COLOMBO	978 116.98	0.057	4	0
02969 O	COLOMBO	978 121.86	0.055	9	0
02969 Q	COLOMBO	978 125.38	0.057	4	0
03302 A	ENTEBBE	977 708.20	0.039	4	0
03302 B	ENTEBBE	977 704.15	0.043	2	0
03302 C	ENTEBBE	977 709.28	0.040	3	0
03302 J	ENTEBBE	977 709.84	0.033	6	7
03302 K	ENTEBBE	977 709.87	0.039	3	1
03398 J	ADDIS ABABA	977 431.19	0.030	16	0
03398 K	ADDIS ABABA	977 466.91	0.028	16	24
03398 L	ADDIS ABABA	977 463.96	0.030	16	0
03405 J	KISANGANI(STANLEYVILLE)	977 864.99	0.068	0	2
03531 J	YAOUNDE	977 847.76	0.054	0	4
03548 J	BANGUI	977 897.85	0.048	0	6
03609 B	LIBREVILLE	978 013.47	0.036	8	7
03609 J	LIBREVILLE	978 022.91	0.038	8	0
03649 B	DOUALA	978 030.24	0.034	8	0
03649 J	DOUALA	978 033.36	0.031	8	23
03661 J	LOME	978 147.80	0.060	0	2
03662 J	COTONOU	978 130.38	0.060	0	2
03663 B	LAGOS	978 121.63	0.030	8	0
03663 J	LAGOS	978 114.40	0.027	18	29
03663 K	LAGOS	978 114.66	0.030	8	0
03663 L	LAGOS	978 114.27	0.031	2	12
03709 J	KANKAN	978 082.67	0.057	0	4
03714 J	BOBO-DIOULASSO	978 107.14	0.057	0	4
03721 J	OUGADOUGOU	978 183.98	0.062	0	2
03728 J	BAMAKO	978 190.16	0.050	0	5
03826 J	ZIGUINCHOR	978 295.08	0.056	0	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
03836 B	BATHURST	978 348.72	0.033	8	0
03836 J	BATHURST	978 338.75	0.030	8	8
03846 A	MBOUR-DAKAR	978 370.34	0.027	17	4
03846 B	MBOUR-DAKAR	978 370.39	0.027	14	0
03846 C	MBOUR-DAKAR	978 466.71	0.031	6	0
03846 D	MBOUR-DAKAR	978 464.50	0.036	2	0
03846 J	MBOUR-DAKAR	978 462.42	0.024	25	25
03846 K	MBOUR-DAKAR	978 462.43	0.037	2	5
03846 L	MBOUR-DAKAR	978 462.36	0.026	12	15
03846 M	MBOUR-DAKAR	978 462.86	0.036	2	0
03846 Q	MBOUR-DAKAR	978 462.29	0.028	12	4
03846 R	MBOUR-DAKAR	978 461.31	0.024	20	0
03846 S	MBOUR-DAKAR	978 461.86	0.022	8	16
03846 T	MBOUR-DAKAR	978 461.34	0.044	2	0
03885 J	NOUAKCHOTT	978 571.58	0.030	0	15
03962 J	CAPE VERDE ISLAND	978 716.46	0.080	0	2
03962 K	CAPE VERDE ISLAND	978 716.50	0.049	0	2
04301 J	PORT OF SPAIN	978 146.88	0.025	22	27
04301 K	PORT OF SPAIN	978 146.87	0.026	15	8
04301 L	PORT OF SPAIN	978 146.89	0.030	5	0
04301 M	PORT OF SPAIN	978 177.18	0.028	10	0
04306 A	CARACAS	978 324.72	0.037	2	13
04306 K	CARACAS	978 231.06	0.027	6	16
04306 L	CARACAS	978 237.24	0.033	4	0
04328 J	CURACAO	978 405.64	0.087	0	4
04341 B	ST.LUCIA	978 514.21	0.028	7	0
04341 J	ST.LUCIA	978 512.81	0.024	7	16
04371 B	ANTIGUA	978 638.91	0.027	7	0
04371 J	ANTIGUA	978 636.58	0.023	7	22
04374 B	ST.CROIX	978 671.23	0.027	6	0
04374 J	ST.CROIX	978 649.29	0.023	6	16
04386 B	SAN JUAN	978 662.02	0.034	8	0
04386 J	SAN JUAN	978 669.88	0.029	8	8
04386 L	SAN JUAN	978 656.03	0.032	4	4
04386 P	SAN JUAN	978 671.14	0.039	8	0
04386 Q	SAN JUAN	978 671.05	0.043	4	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
04387 J	RAMEY	978 644.99	0.021	8	22
04387 K	RAMEY	978 645.01	0.020	8	24
04404 A	BARRANQUILLA	978 228.42	0.034	4	0
04404 J	BARRANQUILLA	978 211.56	0.023	5	18
04404 K	BARRANQUILLA	978 224.27	0.029	9	0
04476 J	KINGSTON	978 583.64	0.027	7	16
04476 K	KINGSTON	978 583.30	0.030	7	0
04476 L	KINGSTON	978 583.73	0.097	0	2
04482 J	PORT AU PRINCE	978 587.68	0.029	7	8
04482 K	PORT AU PRINCE	978 580.72	0.032	7	0
04487 A	MONTEGO BAY	978 660.07	0.031	7	0
04487 J	MONTEGO BAY	978 666.64	0.027	7	16
04495 J	GUANTANAMO	978 731.79	0.026	7	16
04495 K	GUANTANAMO	978 730.55	0.030	7	0
04526 K	MANAGUA	978 270.91	0.022	4	26
04526 L	MANAGUA	978 270.76	0.026	4	4
04539 K	SAN SALVADOR	978 173.58	0.023	8	27
04539 L	SAN SALVADOR	978 173.68	0.026	8	0
04640 K	GUATEMALA	977 966.80	0.023	5	30
04640 L	GUATEMALA	977 967.04	0.026	5	5
04640 M	GUATEMALA	977 967.03	0.037	0	8
04669 J	ACAPULCO	978 501.79	0.035	7	1
04669 K	ACAPULCO	978 501.62	0.032	12	10
04669 O	ACAPULCO	978 509.62	0.034	13	0
04698 A	PASO DE CORTES	977 556.36	0.023	19	50
04698 C	PASO DE CORTES	977 638.32	0.025	2	8
04698 D	PASO DE CORTES	977 555.54	0.024	30	7
04698 E	PASO DE CORTES	977 555.74	0.023	31	8
04698 F	PASO DE CORTES	977 555.86	0.023	12	26
04698 G	PASO DE CORTES	977 555.62	0.024	22	0
04699 A	MEXICO CITY	977 926.50	0.020	216	117
04699 B	MEXICO CITY	977 926.69	0.022	12	4
04699 C	MEXICO CITY	977 926.71	0.020	42	44
04699 D	MEXICO CITY	977 927.15	0.023	8	4
04699 E	MEXICO CITY	977 927.15	0.020	42	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
04699 F	MEXICO CITY	977 926.69	0.021	14	14
04699 H	MEXICO CITY	977 938.68	0.024	8	0
04699 J	MEXICO CITY	977 955.42	0.020	73	60
04699 L	MEXICO CITY	977 955.99	0.019	96	93
04699 M	MEXICO CITY	977 955.39	0.028	3	4
05295 C	HAWAII ISLAND	978 656.25	0.080	2	0
05295 D	HAWAII ISLAND	978 649.85	0.080	2	0
05295 H	HAWAII ISLAND	978 656.63	0.075	4	0
05295 J	HAWAII ISLAND	978 860.76	0.070	2	4
05696 J	WAKE ISLAND	978 862.98	0.080	3	5
05696 K	WAKE ISLAND	978 871.91	0.083	1	1
05696 L	WAKE ISLAND	978 869.47	0.034	2	0
05696 M	WAKE ISLAND	978 863.25	0.041	0	4
05696 N	WAKE ISLAND	978 866.56	0.040	0	8
05834 J	GUAM	978 509.03	0.087	0	4
05834 N	GUAM	978 507.57	0.043	0	6
06050 A	MANILA	978 382.30	0.027	25	9
06050 B	MANILA	978 347.79	0.027	29	2
06050 C	MANILA	978 381.94	0.029	8	6
06050 J	MANILA	978 381.83	0.027	29	6
06050 K	MANILA	978 361.92	0.026	56	4
06050 L	MANILA	978 358.56	0.026	55	32
06050 N	MANILA	978 341.42	0.028	15	0
06050 O	MANILA	978 342.16	0.031	8	0
06050 P	MANILA	978 343.38	0.035	4	0
06050 Q	MANILA	978 344.71	0.034	4	0
06050 R	MANILA	978 344.71	0.034	4	0
06050 S	MANILA	978 346.12	0.033	4	0
06050 T	MANILA	978 358.53	0.029	6	2
06050 X	MANILA	978 341.70	0.030	6	0
06050 Y	MANILA	978 341.79	0.030	7	0
06050 Z	MANILA	978 342.66	0.032	4	0
06206 J	SAIGON	978 215.09	0.027	0	26
06206 K	SAIGON	978 215.07	0.043	0	4
06214 B	PHNOM PENH	978 228.37	0.055	4	0
06214 C	PHNOM PENH	978 227.32	0.055	4	0
06214 J	PHNOM PENH	978 223.08	0.056	4	0
06214 K	PHNOM PENH	978 223.09	0.051	6	2
06214 L	PHNOM PENH	978 195.87	0.055	4	0
06214 M	PHNOM PENH	978 177.93	0.055	4	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
06214 Z	PHNOM PENH	978 223.83	0.050	10	2
06230 A	BANGKOK	978 300.07	0.032	12	0
06230 J	BANGKOK	978 314.85	0.030	26	32
06230 K	BANGKOK	978 314.77	0.031	20	0
06230 L	BANGKOK	978 298.16	0.031	12	0
06230 M	BANGKOK	978 313.53	0.068	0	4
06230 P	BANGKOK	978 300.55	0.035	4	0
06230 Z	BANGKOK	978 297.62	0.032	10	6
06366 J	RANGOON	978 453.82	0.046	4	0
06366 K	RANGOON	978 453.80	0.042	4	8
06366 L	RANGOON	978 453.90	0.064	0	4
06430 A	MADRAS	978 266.55	0.045	8	0
06430 J	MADRAS	978 265.16	0.043	8	8
06537 A	BANGALORE	978 013.89	0.045	8	0
06537 J	BANGALORE	978 023.14	0.044	8	8
06578 J	HYDERABAD	978 319.58	0.042	0	8
06592 J	BOMBAY	978 643.93	0.038	0	8
06592 K	BOMBAY	978 643.90	0.090	4	4
06592 P	BOMBAY	978 617.22	0.092	4	0
06824 J	ADEN	978 304.32	0.094	9	8
06824 M	ADEN	978 308.95	0.094	9	0
06952 A	KHARTOUM	978 288.64	0.024	25	0
06952 B	KHARTOUM	978 288.67	0.023	48	1
06952 C	KHARTOUM	978 288.55	0.024	38	8
06952 D	KHARTOUM	978 286.38	0.024	15	0
06952 E	KHARTOUM	978 288.84	0.024	16	0
06952 K	KHARTOUM	978 288.59	0.022	44	52
06952 L	KHARTOUM	978 288.65	0.023	44	15
06956 J	TESSENEI	978 175.80	0.029	0	16
06958 A	ASMARA	977 805.45	0.027	32	17
06958 J	ASMARA	977 808.26	0.028	23	8
06958 K	ASMARA	977 807.75	0.026	23	23
06997 J	PORT SUDAN	978 622.80	0.029	8	0
06997 K	PORT SUDAN	978 625.99	0.026	8	8
07125 J	FORT LAMY	978 156.24	0.056	0	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
07228 J	KANO	978 120.92	0.040	0	14
07232 J	NIAMEY	978 251.33	0.042	0	6
07407 J	PORT ETIENNE	978 693.79	0.033	0	13
07435 J	VILLA CISNEROS	978 861.09	0.054	0	2
07485 B	GRAND CANARY	979 373.61	0.034	8	0
07485 J	GRAND CANARY	979 361.83	0.031	8	14
08141 A	KEY WEST	978 954.46	0.025	20	8
08141 J	KEY WEST	978 954.07	0.024	12	0
08141 K	KEY WEST	978 957.42	0.044	2	0
08141 M	KEY WEST	978 953.69	0.029	12	0
08141 N	KEY WEST	978 953.88	0.032	6	0
08141 O	KEY WEST	978 957.35	0.021	8	16
08150 A	MIAMI	979 020.95	0.023	11	16
08150 B	MIAMI	979 020.96	0.021	18	0
08150 J	MIAMI	979 038.29	0.018	18	16
08150 L	MIAMI	979 039.57	0.026	2	6
08150 N	MIAMI	979 038.29	0.019	24	0
08150 O	MIAMI	978 972.80	0.019	17	8
08150 P	MIAMI	978 972.83	0.018	14	24
08150 Q	MIAMI	978 975.00	0.022	8	0
08150 R	MIAMI	979 037.04	0.015	8	55
08150 S	MIAMI	979 038.05	0.018	16	0
08160 A	WEST PALM BEACH	979 117.38	0.023	7	0
08160 F	POMPANO BEACH	979 071.48	0.023	7	0
08160 J	WEST PALM BEACH	979 118.70	0.018	23	27
08160 N	POMPANO BEACH	979 071.58	0.018	23	16
08170 B	VERO BEACH	979 159.63	0.022	8	0
08170 J	VERO BEACH	979 159.04	0.019	1	16
08170 K	VERO BEACH	979 159.01	0.018	7	16
08172 J	TAMPA	979 189.59	0.059	0	2
08180 J	COCOA	979 193.19	0.022	0	16
08181 A	ORLANDO	979 216.74	0.017	15	0
08181 B	ORLANDO	979 168.50	0.019	8	0
08181 J	ORLANDO	979 204.09	0.016	21	31
08181 K	ORLANDO	979 207.74	0.014	48	59

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
08181 L	ORLANDO	979 185.84	0.015	36	21
08181 M	ORLANDO	979 191.08	0.015	22	32
08191 B	DAYTONA BEACH	979 267.63	0.020	9	0
08191 F	ST. AUGUSTINE	979 317.37	0.020	9	0
08191 J	DAYTONA BEACH	979 262.50	0.016	25	28
08191 O	ST. AUGUSTINE	979 327.21	0.016	25	16
08227 J	TAMPICO	978 782.10	0.048	0	4
08277 J	CORPUS CHRISTI	979 128.55	0.043	0	4
08279 J	LAREDO	979 064.61	0.019	1	24
08279 K	NUEVO LAREDO	979 062.55	0.020	0	16
08289 B	COTULLA	979 139.38	0.019	0	8
08290 A	NEW ORLEANS	979 312.03	0.018	16	0
08290 J	NEW ORLEANS	979 314.94	0.016	16	23
08295 A	HOUSTON	979 283.72	0.015	62	12
08295 B	HOUSTON	979 283.72	0.018	15	9
08295 D	HOUSTON	979 282.91	0.019	9	0
08295 J	HOUSTON	979 278.66	0.015	17	81
08295 K	HOUSTON	979 278.67	0.015	7	51
08295 M	HOUSTON	979 278.70	0.014	56	17
08295 N	HOUSTON	979 278.66	0.023	5	0
08295 O	HOUSTON	979 278.77	0.016	16	16
08295 P	HOUSTON	979 278.70	0.015	17	19
08295 Q	HOUSTON	979 278.70	0.019	10	0
08298 A	SAN ANTONIO	979 182.73	0.055	3	4
08298 B	SAN ANTONIO	979 180.10	0.016	23	0
08298 J	SAN ANTONIO	979 182.86	0.018	13	4
08298 K	SAN ANTONIO	979 182.83	0.020	9	0
08298 L	SAN ANTONIO	979 182.57	0.015	24	50
08298 M	SAN ANTONIO	979 194.09	0.015	10	83
08298 N	SAN ANTONIO	979 182.75	0.016	17	29
08298 O	SAN ANTONIO	979 183.02	0.016	27	3
08298 X	SAN ANTONIO	979 182.24	0.017	20	4
08320 A	SAN LUIS POTOSI	978 195.10	0.023	14	8
08320 B	SAN LUIS POTOSI	978 194.98	0.034	2	0
08320 J	SAN LUIS POTOSI	978 194.70	0.032	3	0
08320 K	SAN LUIS POTOSI	978 194.78	0.020	11	48
08350 A	MONTERREY	978 790.69	0.016	80	28

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
08350 B	MONTERREY	978 790.71	0.017	47	2
08350 C	MONTERREY	978 790.70	0.017	25	24
08350 J	MONTERREY	978 847.05	0.030	3	0
08350 K	MONTERREY	978 847.02	0.015	77	200
08806 C	MAUI ISLAND	978 874.90	0.024	8	8
08806 D	MAUI ISLAND	978 879.44	0.027	16	0
08806 E	MAUI ISLAND	978 847.53	0.030	16	0
08806 G	MAUI ISLAND	978 778.98	0.033	15	0
08806 I	MAUI ISLAND	978 720.38	0.036	14	0
08806 L	MAUI ISLAND	978 607.08	0.039	15	0
08806 N	MAUI ISLAND	978 535.10	0.041	16	0
08806 Q	MAUI ISLAND	978 457.03	0.043	16	0
08806 S	MAUI ISLAND	978 394.65	0.045	16	0
08806 V	MAUI ISLAND	978 288.47	0.047	16	0
08806 W	MAUI ISLAND	978 216.54	0.049	8	0
08817 A	OAHU-HONOLULU	978 944.90	0.021	16	24
08817 B	OAHU-HONOLULU	978 938.35	0.020	45	13
08817 C	OAHU-HONOLULU	978 944.30	0.020	34	6
08817 E	OAHU-HONOLULU	978 937.96	0.020	25	0
08817 J	OAHU-HONOLULU	978 919.14	0.019	75	68
08817 K	OAHU-HONOLULU	978 924.96	0.021	27	0
08817 L	OAHU-HONOLULU	978 924.39	0.027	10	0
08817 M	OAHU-HONOLULU	978 924.30	0.025	15	0
08817 N	OAHU-HONOLULU	978 924.71	0.026	9	0
08817 O	OAHU-HONOLULU	978 924.68	0.027	7	0
08817 P	OAHU-HONOLULU	978 925.05	0.026	8	0
08817 Q	OAHU-HONOLULU	978 918.93	0.021	18	3
08817 R	OAHU-HONOLULU	978 918.43	0.021	20	4
08817 S	OAHU-HONOLULU	978 918.10	0.030	2	2
08817 T	OAHU-HONOLULU	978 957.36	0.031	3	1
09087 J	MIDWAY	979 484.60	0.073	4	6
09087 P	MIDWAY	979 492.22	0.075	4	0
09651 B	TAIPEI	978 950.20	0.028	8	0
09651 J	TAIPEI	978 959.46	0.025	8	28
09667 A	KADENA	979 112.22	0.026	13	4
09667 J	KADENA	979 119.92	0.024	13	32
09667 L	KADENA	979 104.69	0.032	4	0
09667 M	KADENA	979 102.45	0.032	4	0
09724 A	HONG KONG	978 752.31	0.028	19	4
09724 B	HONG KONG	978 755.85	0.028	25	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
09724 J	HONG KONG	978 757.66	0.027	22	8
09724 K	HONG KONG	978 758.24	0.028	20	0
09724 L	HONG KONG	978 757.62	0.026	31	24
09724 M	HONG KONG	978 761.16	0.027	23	0
09724 N	HONG KONG	978 754.47	0.028	24	0
09724 P	HONG KONG	978 760.20	0.034	4	0
09724 Q	HONG KONG	978 757.61	0.033	4	4
09724 R	HONG KONG	978 757.56	0.033	4	1
10028 J	CALCUTTA	978 792.31	0.039	8	14
10028 K	CALCUTTA	978 789.71	0.041	8	0
10052 J	BANARAS	978 920.99	0.039	0	8
10060 J	LUCKNOW	978 963.77	0.038	0	7
10132 J	AHMEDABAD	978 813.78	0.040	0	8
10143 J	UDAIPUR	978 818.89	0.038	0	16
10165 J	JAIPUR	978 975.42	0.035	0	16
10177 J	AGRA	979 039.79	0.033	0	13
10187 A	NEW DELHI	979 121.55	0.039	4	2
10187 B	NEW DELHI	979 124.13	0.033	12	4
10187 J	NEW DELHI	979 119.38	0.032	18	4
10187 K	NEW DELHI	979 123.16	0.030	22	36
10187 L	NEW DELHI	979 122.10	0.032	16	0
10187 M	NEW DELHI	979 123.92	0.032	22	0
10187 N	NEW DELHI	979 119.34	0.037	4	0
10187 Z	NEW DELHI	979 121.32	0.033	8	0
10511 J	WADI HALFA	978 708.65	0.029	8	0
10511 K	WADI HALFA	978 702.81	0.026	8	8
10542 J	ASWAN	978 854.21	0.035	8	0
10542 K	ASWAN	978 823.15	0.032	8	8
10552 J	LUXOR	978 960.04	0.031	8	0
10552 K	LUXOR	978 948.70	0.029	8	16
10591 B	CAIRO	979 276.76	0.025	18	0
10591 C	CAIRO	979 279.44	0.027	10	0
10591 L	CAIRO	979 301.25	0.024	8	17
10591 M	CAIRO	979 300.34	0.024	24	26

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER		---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
10591	N	CAIRO	979 300.33	0.026	8	0
10871	J	AOULEF	978 971.20	0.049	0	3
10909	J	AGADIR	979 319.63	0.031	9	12
10909	K	AGADIR	979 330.67	0.033	9	0
10918	J	MARRAKECH	979 298.86	0.054	0	2
10937	B	CASABLANCA	979 639.53	0.029	9	0
10937	J	CASABLANCA	979 627.96	0.027	9	30
10950	J	ORAN	979 801.45	0.051	0	2
10955	B	TANGIER	979 718.19	0.028	8	0
10955	J	TANGIER	979 734.01	0.025	16	16
10955	K	TANGIER	979 733.97	0.026	8	4
10966	K	ROTA	979 851.31	0.099	4	4
10966	P	ROTA	979 848.69	0.101	4	0
10989	A	LISBON	980 075.73	0.022	18	4
10989	J	LISBON	980 064.34	0.021	10	17
10989	K	LISBON	980 065.12	0.020	14	23
10989	L	LISBON	980 064.50	0.021	20	0
11187	J	AZORES	980 161.43	0.053	2	11
11187	K	AZORES	980 110.27	0.056	2	0
11187	L	AZORES	980 102.35	0.051	2	2
11524	J	BERMUDA	979 794.02	0.018	0	24
11524	K	BERMUDA	979 802.30	0.055	6	8
11524	M	BERMUDA	979 792.06	0.056	4	4
11524	O	BERMUDA	979 860.05	0.058	6	0
11524	P	BERMUDA	979 808.07	0.057	12	0
11524	Q	BERMUDA	979 859.26	0.059	4	0
11524	R	BERMUDA	979 842.07	0.059	4	0
11629	A	CHARLESTON	979 536.35	0.018	10	18
11629	J	CHARLESTON	979 552.16	0.015	41	23
11629	K	CHARLESTON	979 552.27	0.019	8	0
11629	L	CHARLESTON	979 552.98	0.016	11	43
11629	M	CHARLESTON	979 553.08	0.016	8	20
11629	N	CHARLESTON	979 550.22	0.019	8	0
11649	B	FLORENCE(S.CAROLINA)	979 667.24	0.020	9	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
11649 J	FLORENCE(S.CAROLINA)	979 670.34	0.016	9	43
11658 B	RALEIGH	979 769.86	0.019	9	0
11658 J	RALEIGH	979 787.38	0.014	17	57
11658 K	RALEIGH	979 787.26	0.016	16	8
11658 L	RALEIGH	979 787.33	0.021	8	0
11677 B	RICHMOND	979 940.94	0.019	9	0
11677 J	RICHMOND	979 938.66	0.015	9	42
11687 A	WASHINGTON	980 104.29	0.013	55	0
11687 B	WASHINGTON	980 104.45	0.015	20	0
11687 C	WASHINGTON	980 103.63	0.013	37	0
11687 D	WASHINGTON	980 086.05	0.012	41	52
11687 E	WASHINGTON	980 084.86	0.014	19	0
11687 F	WASHINGTON	980 084.84	0.019	11	24
11687 G	WASHINGTON	980 082.97	0.017	6	0
11687 H	WASHINGTON	980 083.34	0.016	11	0
11687 I	WASHINGTON	980 086.39	0.014	24	1
11687 K	WASHINGTON	980 094.40	0.047	2	0
11687 L	WASHINGTON	980 094.30	0.012	29	48
11687 M	WASHINGTON	980 088.67	0.011	50	58
11687 N	WASHINGTON	980 066.53	0.022	9	17
11687 O	WASHINGTON	980 067.11	0.018	11	2
11687 P	WASHINGTON	980 095.45	0.014	8	27
11687 Q	WASHINGTON	980 066.37	0.021	6	45
11687 R	WASHINGTON	980 078.45	0.011	54	40
11687 U	WASHINGTON	980 067.08	0.017	9	0
11687 V	WASHINGTON	980 101.32	0.016	3	4
11687 X	WASHINGTON	980 100.69	0.018	16	0
11687 Y	WASHINGTON	980 101.32	0.021	10	0
11687 Z	WASHINGTON	980 072.31	0.027	5	0
11701 J	JACKSONVILLE	979 370.97	0.015	21	56
11701 K	JACKSONVILLE	979 370.91	0.020	4	12
11701 L	JACKSONVILLE	979 362.79	0.017	17	0
11711 J	BRUNSWICK	979 434.74	0.018	9	16
11711 K	BRUNSWICK	979 423.42	0.018	9	16
11714 J	ALBANY	979 438.61	0.026	0	8
11720 J	BEAUFORT	979 524.37	0.019	0	15
11721 B	SAVANNAH	979 475.93	0.021	9	0
11721 J	SAVANNAH	979 483.08	0.017	9	38

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
11734 A	ATLANTA	979 523.57	0.022	17	0
11734 B	ATLANTA	979 524.49	0.022	24	0
11734 C	ATLANTA	979 524.55	0.025	9	0
11734 J	ATLANTA	979 506.31	0.018	8	16
11734 K	ATLANTA	979 506.90	0.019	24	8
11750 A	CHARLOTTE	979 728.06	0.020	8	0
11750 J	CHARLOTTE	979 713.43	0.014	8	31
11750 K	CHARLOTTE	979 714.33	0.015	16	16
11753 A	KNOXVILLE	979 700.23	0.021	16	0
11753 B	KNOXVILLE	979 698.58	0.021	8	0
11753 J	KNOXVILLE	979 688.16	0.016	24	32
11753 K	KNOXVILLE	979 697.14	0.024	16	0
11753 L	KNOXVILLE	979 697.45	0.028	8	0
11753 M	KNOXVILLE	979 688.44	0.021	8	0
11759 A	MEMPHIS	979 716.66	0.020	8	0
11759 J	MEMPHIS	979 707.50	0.016	16	24
11759 K	MEMPHIS	979 711.18	0.020	8	0
11785 B	LOUISVILLE	979 946.70	0.023	8	0
11785 J	LOUISVILLE	979 943.67	0.020	8	19
11807 B	AUSTIN	979 270.30	0.016	22	13
11807 C	AUSTIN	979 309.16	0.037	3	0
11807 J	AUSTIN	979 274.60	0.025	4	0
11807 K	AUSTIN	979 274.55	0.016	40	22
11807 L	AUSTIN	979 274.59	0.022	12	0
11807 M	AUSTIN	979 274.72	0.018	11	8
11807 N	AUSTIN	979 274.22	0.025	2	2
11826 A	DALLAS	979 498.85	0.020	16	0
11826 J	DALLAS	979 498.41	0.013	14	92
11826 K	DALLAS	979 499.19	0.016	20	4
11826 L	DALLAS	979 496.61	0.024	8	0
11826 M	DALLAS	979 498.39	0.024	2	2
11842 B	LITTLE ROCK	979 708.84	0.020	8	0
11842 J	LITTLE ROCK	979 709.40	0.015	16	24
11842 K	LITTLE ROCK	979 709.45	0.020	16	0
11842 L	LITTLE ROCK	979 700.89	0.024	8	0
11877 B	WICHITA	979 832.75	0.022	8	0
11877 J	WICHITA	979 826.26	0.018	16	20
11877 K	WICHITA	979 825.75	0.022	8	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
11880 A	ST.LOUIS	979 983.72	0.021	21	7
11880 B	ST.LOUIS	979 983.79	0.024	9	0
11880 J	ST.LOUIS	979 989.52	0.023	8	0
11880 L	ST.LOUIS	979 989.47	0.020	8	12
11880 M	ST.LOUIS	979 988.25	0.019	24	7
11894 B	KANSAS CITY	979 972.67	0.023	16	0
11894 J	KANSAS CITY	979 985.46	0.020	8	12
11894 K	KANSAS CITY	979 985.46	0.019	16	7
11894 L	KANSAS CITY	979 944.36	0.026	8	0
11916 A	EL PASO	979 107.53	0.021	8	0
11916 J	EL PASO	979 066.93	0.017	24	24
11916 K	EL PASO	979 066.81	0.021	16	0
11916 L	EL PASO	979 066.81	0.025	8	0
11916 M	EL PASO	979 070.44	0.021	8	0
11926 J	ALAMOGORDO	979 116.32	0.019	8	8
11926 K	ALAMOGORDO	979 110.57	0.023	8	0
11931 J	LUBBOCK	979 308.36	0.018	0	16
11951 A	AMARILLO	979 409.11	0.023	4	8
11951 B	AMARILLO	979 408.86	0.018	4	6
11951 J	AMARILLO	979 408.87	0.015	12	36
11951 L	AMARILLO	979 408.47	0.020	8	0
11956 B	ALBUQUERQUE	979 210.62	0.021	8	0
11956 J	ALBUQUERQUE	979 194.01	0.016	24	30
11956 K	ALBUQUERQUE	979 193.51	0.021	8	0
11956 L	ALBUQUERQUE	979 193.51	0.021	8	0
11994 A	DENVER	979 597.68	0.012	112	111
11994 B	DENVER	979 597.10	0.016	19	4
11994 C	DENVER	979 597.64	0.014	45	0
11994 D	DENVER	979 596.53	0.018	19	0
11994 E	DENVER	979 604.65	0.024	7	0
11994 J	DENVER	979 618.97	0.012	63	40
11994 K	DENVER	979 618.48	0.014	22	88
11994 L	DENVER	979 604.60	0.017	13	1
11994 M	DENVER	979 604.24	0.013	43	49
11994 N	DENVER	979 618.22	0.012	53	175
11994 O	DENVER	979 618.64	0.014	15	22
11994 P	DENVER	979 616.85	0.013	8	52
11994 Q	DENVER	979 618.42	0.028	2	5
11994 R	DENVER	979 616.26	0.017	9	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
11998 B	GRAND JUNCTION	979 623.48	0.020	8	0
11998 J	GRAND JUNCTION	979 606.59	0.015	8	20
12027 J	SAN DIEGO	979 522.32	0.060	9	0
12027 K	SAN DIEGO	979 518.54	0.054	4	8
12027 L	SAN DIEGO	979 535.53	0.065	4	0
12027 P	SAN DIEGO	979 527.64	0.063	9	0
12027 Q	SAN DIEGO	979 516.31	0.057	8	0
12032 A	PHOENIX	979 464.16	0.018	12	4
12032 J	PHOENIX	979 476.83	0.017	20	20
12032 K	PHOENIX	979 476.95	0.021	16	0
12032 L	PHOENIX	979 476.98	0.025	8	0
12038 A	LOS ANGELES	979 583.09	0.026	8	0
12038 B	LOS ANGELES	979 583.10	0.018	25	2
12038 C	LOS ANGELES	979 583.88	0.022	16	0
12038 J	LOS ANGELES	979 582.32	0.020	16	0
12038 K	LOS ANGELES	979 582.52	0.016	28	32
12038 L	LOS ANGELES	979 580.00	0.024	16	0
12038 M	LOS ANGELES	979 580.00	0.027	9	0
12038 N	LOS ANGELES	979 634.95	0.024	4	0
12047 J	ONTARIO	979 523.29	0.061	3	1
12047 K	ONTARIO	979 521.40	0.059	3	3
12048 B	PASADENA	979 563.86	0.072	1	1
12048 C	PASADENA	979 564.44	0.071	2	0
12048 J	PASADENA	979 567.15	0.068	1	1
12065 B	LAS VEGAS	979 586.45	0.024	8	0
12065 J	LAS VEGAS	979 592.81	0.016	16	23
12065 K	LAS VEGAS	979 590.37	0.021	16	0
12065 L	LAS VEGAS	979 592.77	0.021	8	0
12099 B	RENO	979 674.65	0.020	8	0
12099 J	RENO	979 675.22	0.015	16	20
12099 K	RENO	979 675.38	0.020	8	0
12172 A	SAN FRANCISCO	979 972.13	0.015	67	32
12172 B	SAN FRANCISCO	979 923.04	0.024	2	0
12172 E	SAN FRANCISCO	979 972.24	0.020	8	0
12172 J	SAN FRANCISCO	979 973.81	0.027	4	6
12172 K	SAN FRANCISCO	979 973.75	0.016	34	15
12172 L	SAN FRANCISCO	979 973.76	0.019	7	4
12172 M	SAN FRANCISCO	979 973.74	0.032	2	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
12172 N	SAN FRANCISCO	979 972.45	0.030	2	0
12172 O	SAN FRANCISCO	979 972.37	0.012	18	74
12172 P	SAN FRANCISCO	979 975.38	0.019	13	0
12172 Q	SAN FRANCISCO	979 975.86	0.017	21	0
12172 R	SAN FRANCISCO	979 983.31	0.016	24	0
12172 T	SAN FRANCISCO	979 975.86	0.020	8	0
12172 U	SAN FRANCISCO	979 950.82	0.019	11	5
12172 V	SAN FRANCISCO	979 927.48	0.023	4	4
12172 W	SAN FRANCISCO	979 970.33	0.021	7	12
12172 X	SAN FRANCISCO	979 974.65	0.015	8	22
12172 Y	SAN FRANCISCO	979 972.06	0.018	12	6
12172 Z	SAN FRANCISCO	979 973.03	0.029	2	3
12181 J	FAIRFIELD	979 975.43	0.015	1	49
12181 K	FAIRFIELD	979 975.40	0.046	1	4
13080 A	TOHOKU	980 094.95	0.031	0	10
13080 J	TOHOKU	980 103.40	0.024	0	8
13110 A	KAGOSHIMA	979 472.15	0.032	14	12
13110 H	KAGOSHIMA	979 471.71	0.034	6	2
13110 J	KAGOSHIMA	979 468.82	0.031	7	8
13110 K	KAGOSHIMA	979 468.92	0.032	5	5
13120 A	KUMAMOTO	979 551.62	0.037	0	14
13130 A	KYUSHU	979 626.59	0.034	10	0
13130 J	KYUSHU	979 634.71	0.035	5	4
13130 K	KYUSHU	979 633.37	0.033	5	4
13145 J	ITAMI	979 703.75	0.026	0	17
13155 A	KYOTO	979 707.27	0.032	9	2
13155 C	KYOTO	979 707.75	0.030	9	14
13159 A	TOKYO	979 787.22	0.025	7	7
13159 B	TOKYO	979 788.72	0.019	30	0
13159 C	TOKYO	979 763.19	0.018	80	57
13159 E	TOKYO	979 791.96	0.018	49	20
13159 H	TOKYO	979 775.91	0.025	4	0
13159 I	TOKYO	979 749.86	0.034	2	0
13159 L	TOKYO	979 759.16	0.034	2	0
13159 M	TOKYO	979 759.19	0.031	2	0
13159 N	TOKYO	979 758.06	0.018	67	48
13159 O	TOKYO	979 758.17	0.023	7	3
13159 P	TOKYO	979 774.09	0.020	21	14

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
13159 Q	TOKYO	979 791.25	0.022	18	1
13159 R	TOKYO	979 773.98	0.017	64	35
13159 S	TOKYO	979 774.01	0.021	9	12
13276 J	SEOUL	979 958.63	0.051	13	2
13276 K	SEOUL	979 958.47	0.052	3	1
13276 L	SEOUL	979 956.45	0.052	12	0
13707 J	MOHAN	979 101.07	0.037	0	16
13708 A	DEHRA DUN	979 049.09	0.041	8	8
13708 J	DEHRA DUN	978 806.72	0.043	8	0
13714 J	AMRITSAR	979 335.06	0.033	0	8
13849 B	KABUL	979 115.08	0.035	8	0
13849 J	KABUL	979 131.53	0.032	16	13
13849 K	KABUL	979 125.33	0.033	32	0
13849 L	KABUL	979 126.20	0.035	8	0
13951 B	TEHERAN	979 387.92	0.031	17	0
13951 C	TEHERAN	979 388.25	0.034	8	0
13951 J	TEHERAN	979 430.68	0.029	9	15
14112 J	PORT SAID	979 432.27	0.030	9	0
14112 K	PORT SAID	979 437.64	0.027	9	8
14135 A	BEIRUT	979 676.25	0.028	12	0
14135 B	BEIRUT	979 686.02	0.029	8	0
14135 J	BEIRUT	979 678.64	0.025	12	22
14135 K	BEIRUT	979 677.44	0.029	10	0
14192 B	ANKARA	979 925.15	0.025	16	0
14192 J	ANKARA	979 909.39	0.022	16	16
14192 K	ANKARA	979 909.26	0.025	16	0
14192 L	ANKARA	979 939.02	0.026	16	0
14192 M	ANKARA	979 935.48	0.026	16	0
14323 A	TRIPOLI	979 572.72	0.021	18	14
14323 K	TRIPOLI	979 572.74	0.022	24	7
14323 L	TRIPOLI	979 523.00	0.025	9	1
14323 N	TRIPOLI	979 525.60	0.039	1	4
14374 J	ETNA MET. OBS.	979 616.87	0.028	25	4
14374 L	ETNA CAS. FORESTALE	979 665.13	0.028	58	0
14374 N	ETNA SANT PAOLO	979 710.53	0.027	50	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
14374 P	ETNA VILLA FORTUNA	979 734.85	0.026	58	8
14374 R	ETNA KM 18	979 768.64	0.026	48	0
14374 T	ETNA KM 15-16	979 804.26	0.025	25	25
14375 A	CATANIA	980 031.88	0.022	19	12
14375 B	CATANIA	980 031.15	0.021	88	18
14375 J	CATANIA	980 044.22	0.021	19	14
14375 K	CATANIA	980 034.63	0.032	2	1
14375 P	FIUMEFREDDO	979 991.43	0.022	24	24
14375 Q	CONTRADA CIBALI	979 998.36	0.022	37	0
14375 R	S. GIOV. DI GALERMO	979 966.93	0.023	50	0
14375 S	MASCALUCIA	979 932.38	0.023	66	0
14375 U	MASSA ANNUNZIATA	979 903.49	0.024	48	0
14375 V	NICOLOSI	979 872.92	0.024	50	0
14375 X	S.BERNARDO	979 844.23	0.024	35	35
14385 J	GALATI MARINA	980 064.68	0.021	58	12
14385 K	GALATI MARINA	980 064.19	0.025	8	0
14385 N	BAGNARA	980 087.07	0.022	33	8
14385 P	VILLA S.GIOVANNI	980 091.15	0.022	57	7
14385 R	MESSINA	980 089.15	0.022	54	0
14385 S	CONTRADA CISTERNE	980 094.87	0.022	21	22
14385 T	ALI TERME	980 028.88	0.022	27	27
14386 J	FALERNA MARINA	980 154.20	0.021	26	38
14386 L	PIZZO CALABRO	980 131.15	0.022	47	7
14386 N	CONTRADA BARRACONE	980 105.72	0.022	21	21
14395 J	PRAIA MARE	980 207.27	0.020	21	21
14395 L	DIAMANTE	980 215.76	0.020	51	15
14395 N	CETRARO	980 211.16	0.021	30	30
14396 J	S.LUCIDO	980 184.82	0.021	0	60
14463 A	ALGIERS	979 896.83	0.041	2	0
14463 J	ALGIERS	979 891.39	0.031	1	8
14463 K	ALGIERS	979 889.61	0.044	1	2
14492 J	MALLORCA	980 163.10	0.033	8	7
14492 K	MALLORCA	980 161.75	0.036	8	0
14503 A	MADRID	979 966.52	0.023	19	0
14503 B	MADRID	979 966.32	0.025	9	1
14503 C	MADRID	979 955.61	0.021	23	0
14503 J	MADRID	979 984.14	0.024	10	3
14503 K	MADRID	979 984.11	0.021	11	6

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
14503 L	MADRID	979 977.18	0.035	2	0
14503 M	MADRID	979 992.51	0.019	41	23
14503 N	MADRID	979 981.35	0.019	23	23
15148 B	BANGOR	980 580.76	0.016	17	0
15148 J	BANGOR	980 576.45	0.015	9	40
15148 K	BANGOR	980 578.94	0.015	8	14
15167 B	CARIBOU	980 725.93	0.020	9	0
15167 J	CARIBOU	980 717.49	0.016	9	40
15203 K	NEW YORK CITY	980 211.35	0.020	9	0
15203 M	NEW YORK CITY	980 211.61	0.021	7	0
15203 Q	NEW YORK CITY	980 257.36	0.015	17	0
15203 R	NEW YORK CITY	980 212.59	0.013	31	32
15203 S	NEW YORK CITY	980 267.77	0.014	16	8
15204 A	PRINCETON	980 163.73	0.015	22	0
15204 B	PRINCETON	980 163.06	0.023	6	0
15204 C	PRINCETON	980 160.98	0.025	5	0
15204 D	PRINCETON	980 160.86	0.025	1	8
15204 E	PRINCETON	980 162.41	0.022	8	0
15204 F	PRINCETON	980 161.82	0.025	4	0
15204 J	PRINCETON	980 198.36	0.012	13	93
15204 K	PRINCETON	980 198.42	0.021	4	3
15204 L	PRINCETON	980 226.89	0.016	11	8
15209 A	PITTSBURGH	980 100.36	0.021	7	0
15209 J	PITTSBURGH	980 084.46	0.016	7	20
15212 A	MIDDLETOWN	980 305.32	0.022	1	8
15212 B	MIDDLETOWN	980 301.50	0.018	10	0
15212 J	MIDDLETOWN	980 297.86	0.014	9	44
15221 A	BOSTON	980 378.70	0.014	5	5
15221 B	BOSTON	980 380.32	0.015	11	0
15221 C	BOSTON	980 385.52	0.017	16	0
15221 D	BOSTON	980 385.62	0.016	16	0
15221 J	BOSTON	980 381.99	0.012	27	61
15221 O	BOSTON	980 389.24	0.014	31	0
15221 P	BOSTON	980 389.89	0.012	21	43
15221 Q	BOSTON	980 389.54	0.014	23	8
15228 A	BUFFALO	980 352.26	0.020	7	0
15228 J	BUFFALO	980 350.72	0.014	7	32
15230 B	PORTLAND(MAINE)	980 501.15	0.020	9	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
15230 J	PORTLAND(MAINE)	980 496.89	0.015	9	33
15236 A	SYRACUSE	980 368.41	0.021	8	0
15236 B	SYRACUSE	980 367.10	0.017	31	0
15236 J	SYRACUSE	980 382.70	0.015	29	16
15236 K	SYRACUSE	980 382.08	0.021	6	0
15239 J	TORONTO	980 415.80	0.015	22	32
15239 K	TORONTO	980 428.90	0.025	8	0
15239 L	TORONTO	980 415.09	0.019	13	22
15239 M	TORONTO	980 434.65	0.022	14	0
15239 N	TORONTO	980 414.60	0.019	21	4
15253 J	MONTREAL	980 629.24	0.014	66	96
15253 K	MONTREAL	980 630.09	0.016	16	11
15253 L	MONTREAL	980 637.23	0.018	20	0
15253 M	MONTREAL	980 637.25	0.016	44	0
15253 N	MONTREAL	980 629.24	0.016	22	0
15253 R	MONTREAL	980 629.08	0.029	4	0
15255 A	OTTAWA	980 606.14	0.022	7	0
15255 D	OTTAWA	980 607.10	0.021	12	32
15255 E	OTTAWA	980 606.85	0.013	119	42
15255 F	OTTAWA	980 606.08	0.017	25	0
15255 H	OTTAWA	980 614.06	0.020	11	0
15255 J	OTTAWA	980 603.79	0.013	59	67
15255 L	OTTAWA	980 604.14	0.015	46	18
15255 M	OTTAWA	980 606.79	0.018	21	0
15255 P	OTTAWA	980 614.02	0.024	8	0
15261 J	QUEBEC	980 725.68	0.020	74	20
15261 L	QUEBEC	980 725.92	0.023	24	0
15261 M	QUEBEC	980 719.51	0.024	16	0
15261 N	QUEBEC	980 725.66	0.022	28	2
15261 O	QUEBEC	980 732.67	0.022	34	0
15261 P	QUEBEC	980 714.77	0.026	10	0
15282 J	ROBERVAL	980 828.30	0.017	34	34
15282 K	ROBERVAL	980 842.57	0.019	34	0
15282 L	ROBERVAL	980 843.09	0.020	30	0
15282 M	ROBERVAL	980 842.81	0.020	26	0
15282 N	ROBERVAL	980 849.62	0.027	6	0
15303 C	COLUMBUS	980 081.40	0.021	16	0
15303 J	COLUMBUS	980 064.21	0.018	16	19
15317 A	CHICAGO	980 272.62	0.025	11	6

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
15317 B	CHICAGO	980 279.32	0.017	25	0
15317 C	CHICAGO	980 271.04	0.024	9	0
15317 D	CHICAGO	980 270.37	0.020	24	0
15317 J	CHICAGO	980 271.79	0.023	17	0
15317 M	CHICAGO	980 274.12	0.014	24	20
15317 N	CHICAGO	980 273.87	0.015	16	16
15317 O	CHICAGO	980 274.47	0.020	8	0
15323 A	DETROIT	980 322.97	0.020	8	0
15323 J	DETROIT	980 303.68	0.016	16	15
15323 K	DETROIT	980 304.46	0.016	24	8
15323 L	DETROIT	980 304.08	0.020	8	0
15323 M	DETROIT	980 336.84	0.020	8	0
15339 A	MADISON	980 354.22	0.013	59	66
15339 B	MADISON	980 354.13	0.022	9	2
15339 C	MADISON	980 354.15	0.019	19	6
15339 D	MADISON	980 354.14	0.017	17	0
15339 E	MADISON	980 354.21	0.019	6	0
15339 F	MADISON	980 351.42	0.020	9	0
15339 G	MADISON	980 339.18	0.017	11	0
15339 H	MADISON	980 342.10	0.018	8	2
15339 J	MADISON	980 357.82	0.012	48	62
15339 K	MADISON	980 357.84	0.016	18	9
15339 O	MADISON	980 358.91	0.017	8	0
15414 J	STUART	980 193.95	0.034	0	2
15416 J	FREMONT	980 165.25	0.034	0	12
15426 B	SIOUX CITY	980 294.98	0.019	8	0
15426 J	SIOUX CITY	980 292.98	0.015	8	24
15436 B	SIOUX FALLS	980 345.21	0.020	8	0
15436 J	SIOUX FALLS	980 347.49	0.015	16	24
15436 K	SIOUX FALLS	980 347.52	0.020	8	0
15443 A	MINNEAPOLIS	980 583.22	0.017	16	6
15443 K	MINNEAPOLIS	980 580.92	0.014	20	19
15443 L	MINNEAPOLIS	980 580.97	0.012	8	61
15462 B	DULUTH	980 746.61	0.020	8	0
15462 J	DULUTH	980 695.82	0.015	8	13
15466 J	FARGO	980 712.66	0.023	0	8
15477 J	GRAND FORKS	980 794.21	0.026	8	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
15477 K	GRAND FORKS	980 782.38	0.026	8	0
15477 M	GRAND FORKS	980 791.96	0.022	16	7
15497 B	WINNIPEG	980 980.03	0.022	46	0
15497 C	WINNIPEG	980 977.84	0.022	39	0
15497 D	WINNIPEG	980 979.84	0.022	34	0
15497 J	WINNIPEG	980 977.56	0.021	22	8
15497 K	WINNIPEG	980 977.54	0.023	22	0
15497 L	WINNIPEG	980 977.66	0.024	6	10
15497 O	WINNIPEG	980 976.76	0.020	44	22
15497 P	WINNIPEG	980 996.83	0.027	11	0
15514 A	CHEYENNE	979 686.18	0.016	31	3
15514 B	CHEYENNE	979 686.30	0.023	9	0
15514 J	CHEYENNE	979 686.23	0.015	16	17
15514 K	CHEYENNE	979 686.42	0.013	30	31
15514 L	CHEYENNE	979 686.18	0.019	12	0
15514 M	CHEYENNE	979 686.17	0.013	20	57
15514 N	CHEYENNE	979 684.32	0.013	26	20
15514 O	CHEYENNE	979 686.74	0.014	12	15
15526 J	CASPER	979 941.59	0.022	4	2
15526 K	CASPER	979 941.41	0.014	11	34
15526 L	CASPER	979 941.32	0.013	7	45
15543 B	RAPID CITY	980 257.16	0.019	8	0
15543 J	RAPID CITY	980 237.08	0.014	8	23
15546 A	SHERIDAN	980 212.05	0.013	25	11
15546 C	SHERIDAN	980 228.35	0.015	18	0
15546 J	SHERIDAN	980 212.14	0.012	51	111
15546 K	SHERIDAN	980 212.06	0.012	36	23
15558 A	BILLINGS	980 356.37	0.014	18	13
15558 K	BILLINGS	980 357.37	0.014	8	30
15558 L	BILLINGS	980 357.32	0.013	10	35
15558 M	BILLINGS	980 357.29	0.012	16	32
15560 B	BISMARCK	980 611.76	0.023	8	0
15560 J	BISMARCK	980 612.75	0.019	16	0
15560 K	BISMARCK	980 613.04	0.014	8	31
15581 J	MINOT	980 782.79	0.022	8	0
15581 L	MINOT	980 761.91	0.018	8	14
15601 J	SALT LAKE CITY	979 801.61	0.014	12	33

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
15601 K	SALT LAKE CITY	979 801.70	0.016	36	12
15601 L	SALT LAKE CITY	979 792.44	0.020	8	0
15601 M	SALT LAKE CITY	979 792.46	0.020	8	0
15601 N	SALT LAKE CITY	979 770.63	0.020	8	0
15611 J	OGDEN	979 786.08	0.019	8	8
15611 K	OGDEN	979 785.76	0.023	16	0
15611 L	OGDEN	979 793.71	0.026	8	0
15636 B	BOISE	980 203.64	0.020	8	0
15636 J	BOISE	980 193.64	0.015	8	21
15671 A	GREAT FALLS	980 512.30	0.012	58	16
15671 B	GREAT FALLS	980 512.35	0.012	51	0
15671 C	GREAT FALLS	980 513.27	0.013	27	43
15671 J	GREAT FALLS	980 499.11	0.012	53	12
15671 K	GREAT FALLS	980 514.52	0.016	11	2
15671 L	GREAT FALLS	980 514.49	0.011	78	171
15671 M	GREAT FALLS	980 517.95	0.018	6	0
15671 N	GREAT FALLS	980 499.31	0.012	40	26
15671 O	GREAT FALLS	980 498.93	0.013	24	27
15671 P	GREAT FALLS	980 499.11	0.015	8	12
15671 Q	GREAT FALLS	980 499.15	0.015	3	20
15671 X	GREAT FALLS	980 513.30	0.024	3	0
15677 B	SPOKANE	980 659.71	0.019	8	0
15677 J	SPOKANE	980 633.04	0.014	16	24
15677 K	SPOKANE	980 631.78	0.019	16	0
15677 L	SPOKANE	980 628.41	0.023	8	0
15682 B	CUTBANK	980 593.83	0.094	1	2
15683 J	BROWNING	980 541.74	0.097	0	2
15692 A	LETHBRIDGE	980 744.02	0.026	2	22
15692 C	LETHBRIDGE	980 744.18	0.032	2	0
15692 J	LETHBRIDGE	980 739.15	0.017	2	8
15722 B	MEDFORD	980 213.99	0.020	8	0
15722 J	MEDFORD	980 221.90	0.015	8	19
15752 B	PORTLAND(OREGON)	980 632.66	0.022	8	0
15752 J	PORTLAND(OREGON)	980 633.62	0.013	8	39
15752 K	PORTLAND(OREGON)	980 633.80	0.018	16	0
15772 A	SEATTLE	980 724.34	0.017	31	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
15772 B	SEATTLE	980 724.36	0.021	17	0
15772 C	SEATTLE	980 724.05	0.023	9	0
15772 D	SEATTLE	980 725.44	0.020	15	0
15772 J	SEATTLE	980 761.78	0.015	40	0
15772 K	SEATTLE	980 762.02	0.035	3	0
15772 N	SEATTLE	980 760.97	0.068	2	0
15772 P	SEATTLE	980 760.79	0.013	19	55
15772 Q	SEATTLE	980 723.49	0.025	8	0
15772 R	SEATTLE	980 761.98	0.021	6	0
15793 A	VANCOUVER	980 920.68	0.016	93	0
15793 B	VANCOUVER	980 920.52	0.016	44	0
15793 C	VANCOUVER	980 943.64	0.021	7	0
15793 J	VANCOUVER	980 915.41	0.015	70	14
15793 K	VANCOUVER	980 915.41	0.016	45	2
15793 N	VANCOUVER	980 938.24	0.019	23	0
15793 M	VANCOUVER	980 915.97	0.014	33	22
15793 O	VANCOUVER	980 938.33	0.017	37	0
15793 Q	VANCOUVER	980 926.28	0.033	2	0
15793 R	VANCOUVER	980 915.37	0.029	3	0
15793 T	VANCOUVER	980 920.53	0.026	4	0
15793 U	VANCOUVER	980 915.68	0.019	21	0
16601 J	MISAWA	980 308.08	0.021	0	26
16631 A	SAPPORO	980 476.96	0.020	30	13
16631 B	SAPPORO	980 427.35	0.021	14	18
16631 C	SAPPORO	980 475.92	0.027	4	0
16631 J	SAPPORO	980 427.34	0.022	18	0
16631 K	SAPPORO	980 426.52	0.020	40	20
16651 A	WAKKANAI	980 643.86	0.028	5	9
16651 J	WAKKANAI	980 634.65	0.028	5	5
17840 A	BELGRADE	980 558.87	0.063	2	0
17840 B	BELGRADE	980 591.37	0.063	2	0
17840 J	BELGRADE	980 592.54	0.055	2	2
17904 B	NAPLES	980 229.50	0.029	3	0
17904 J	ANGRI	980 265.37	0.017	51	17
17904 K	ANGRI	980 261.64	0.021	8	0
17904 L	ANGRI	980 265.53	0.018	15	3
17904 P	LICOLA	980 272.66	0.017	29	36
17904 R	PONTECAGNANO	980 242.04	0.016	24	24
17905 J	PONTE FIUME FARAONE	980 172.03	0.019	60	8

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
17905 L	BIVIO GIUNGANO	980 238.84	0.018	32	32
17905 N	VALLOSCALO	980 224.26	0.019	54	0
17905 P	SAPRI	980 200.60	0.019	32	32
17905 Z	SAPRI HOTEL	980 200.74	0.022	8	4
17912 A	ROME	980 349.23	0.013	71	78
17912 B	ROME	980 347.22	0.019	11	0
17912 C	ROME	980 178.43	0.025	18	0
17912 D	ROME	980 347.65	0.028	2	0
17912 E	ROME	980 347.80	0.014	48	0
17912 F	ROME	980 347.94	0.013	103	7
17912 G	ROME	980 206.66	0.022	31	0
17912 H	ROME	980 127.36	0.028	11	0
17912 J	ROME	980 334.27	0.023	7	0
17912 K	ROME	980 332.56	0.024	5	0
17912 L	ROME	980 332.39	0.014	31	21
17912 M	ROME	980 333.19	0.020	9	0
17912 N	ROME	980 361.76	0.012	69	42
17912 O	ROME	980 361.48	0.015	14	30
17912 P	ROME	980 361.64	0.018	9	0
17912 Q	ROME	980 361.65	0.019	8	0
17912 R	ROME	980 361.54	0.013	33	25
17912 S	ROME	980 360.23	0.022	4	1
17912 W	ROME	980 343.66	0.015	18	0
17912 X	ROME	980 277.32	0.017	27	0
17912 Y	CASALE VACCINA	980 378.70	0.014	35	31
17912 Z	BIVIO CISTERNA	980 321.91	0.015	30	30
17912 1	ROME	980 344.47	0.020	4	2
17912 2	ROME	980 360.51	0.017	11	4
17912 3	ROME	980 360.86	0.014	28	3
17912 4	ROME	980 347.48	0.013	40	15
17913 J	TERRACINA	980 332.67	0.017	11	7
17913 K	TERRACINA	980 332.52	0.016	18	14
17913 N	MINTURNO	980 299.00	0.016	17	37
17921 J	PODERE SPINETA	980 452.23	0.015	29	44
17921 L	PODERE S. GUISEPPE	980 423.36	0.015	56	10
17921 N	CASCINALE VALIARDA	980 401.80	0.015	27	27
17930 J	QUERCETA	980 535.72	0.017	26	32
17930 L	PINETA	980 504.38	0.021	8	0
17930 N	CASTIGLIONCELLO	980 505.91	0.017	52	8
17930 P	PODERE CASACCIA	980 474.60	0.016	26	26
17940 J	LUZZARA	980 497.72	0.018	24	24

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
17940 L	S.CROCE BORETTO	980 467.80	0.019	50	2
17940 N	PEDRIGNANO	980 437.49	0.018	54	5
17940 P	RICO	980 407.28	0.019	40	22
17940 R	PIANTONIA	980 376.80	0.019	16	16
17941 B	BOLOGNA	980 427.70	0.020	7	3
17941 F	FERRARA	980 588.76	0.019	7	8
17950 J	PERI	980 647.36	0.018	34	34
17950 K	PERI	980 646.69	0.020	8	8
17950 N	CA BRUSA	980 618.87	0.018	43	5
17950 P	AZIENDA PRESTINARI	980 589.54	0.018	42	4
17950 R	MANTOVA	980 558.79	0.017	51	17
17950 T	CORTE MORELLINA	980 529.59	0.018	26	26
17951 G	ROVERETO	980 614.32	0.018	0	42
17953 A	TRIESTE	980 650.41	0.079	2	2
17953 C	TRIESTE	980 650.96	0.084	4	0
17953 G	TRIESTE	980 650.01	0.084	4	0
17955 J	ZAGREB	980 658.38	0.056	0	2
17961 J	COLLE ISARCO	980 409.07	0.020	27	28
17961 L	CAMPO DI TRENS	980 438.12	0.021	39	0
17961 N	FORTEZZA	980 466.88	0.021	36	0
17961 P	VARNA	980 495.41	0.021	37	0
17961 R	CHIUSA	980 525.17	0.020	42	0
17961 T	LAIVES	980 556.18	0.019	48	8
17961 V	GARDOLO	980 583.24	0.019	23	23
17961 Z	BOLZANO	980 563.39	0.021	0	16
17971 J	INNSBRUCK	980 554.62	0.019	25	0
17971 K	INNSBRUCK	980 554.64	0.019	35	2
17971 L	INNSBRUCK	980 552.75	0.019	8	15
17971 P	FOCHING	980 646.88	0.021	5	6
17971 Q	IRSCHENBERG	980 617.66	0.021	5	6
17971 R	STRASS	980 585.31	0.019	20	20
17971 S	KOLSASS	980 563.39	0.023	8	0
17971 T	MUTTERS	980 529.21	0.020	36	0
17971 U	SCHONBERG SILLWERKE	980 510.38	0.020	43	9
17971 V	SCHONBERG ALTE POST	980 472.95	0.020	36	0
17971 W	MATREI	980 447.88	0.020	42	2
17971 X	STAFFLACH	980 412.31	0.020	22	20
17971 Y	GRIES AM BRENNER	980 381.62	0.034	2	0
17971 Z	BRENNER	980 353.03	0.026	3	3

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
17972 J	PFRAUNDORF	980 668.34	0.018	14	14
17972 L	NIEDERAUDORF	980 652.29	0.018	34	24
17972 N	KUFSTEIN	980 637.02	0.020	20	0
17972 P	WORGL	980 609.03	0.019	20	20
17981 A	MUNICH	980 723.15	0.017	32	18
17981 B	MUNICH	980 729.53	0.017	21	10
17981 C	MUNICH	980 729.06	0.016	77	8
17981 D	MUNICH	980 731.34	0.018	21	0
17981 E	MUNICH	980 712.52	0.016	24	28
17981 F	MUNICH	980 724.68	0.021	6	4
17981 J	MUNICH	980 714.14	0.015	10	48
17981 K	MUNICH	980 714.44	0.016	34	8
17981 L	MUNICH	980 714.15	0.042	1	4
17981 P	DENKENDORF	980 843.76	0.016	25	25
17981 R	INGOLSTADT	980 857.59	0.016	29	11
17981 T	LANGENBRUCK	980 821.89	0.016	64	8
17981 V	SCHWEITENKIRCHEN	980 778.32	0.017	52	0
17981 X	ECHING	980 754.88	0.016	56	0
17990 B	BAMBERG SUD	980 986.20	0.017	0	60
17991 A	NURNBERG	980 918.65	0.024	8	0
17991 C	NURNBERG SUD	980 897.90	0.017	52	12
17991 D	NURNBERG	980 924.47	0.017	56	2
17991 J	NURNBERG	980 937.38	0.020	18	0
17991 K	NURNBERG	980 937.44	0.018	8	16
17991 P	NEUSES	980 966.51	0.017	26	30
17991 R	ERLANGEN SUD	980 941.92	0.019	18	0
17991 T	ALLERSBERG	980 879.28	0.017	21	3
17991 V	GREDING	980 863.90	0.016	25	25
18012 J	BARCELONA	980 306.23	0.025	9	15
18012 L	BARCELONA	980 306.39	0.027	9	2
18022 J	PERPIGNAN	980 394.14	0.035	0	8
18030 A	BAGNERES	980 272.26	0.031	12	7
18030 L	TARBES	980 344.74	0.031	8	8
18030 P	SAINT-GAUDENS	980 328.82	0.032	4	4
18031 A	TOULOUSE	980 427.74	0.025	17	15
13031 B	TOULOUSE	980 427.76	0.027	13	0
18031 C	TOULOUSE	980 428.36	0.031	2	4
18031 J	TOULOUSE	980 438.84	0.025	16	26
18031 K	TOULOUSE	980 438.80	0.034	4	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
18031 X	CAPENS	980 388.03	0.032	2	2
18033	NARBONNE	980 450.75	0.032	0	6
18035 C	MARSEILLES	980 457.10	0.029	4	6
18035 D	MARSEILLES	980 457.85	0.041	2	0
18035 J	MARSEILLES	980 473.55	0.029	3	6
18035 M	MARSEILLES	980 482.36	0.041	2	0
18040 J	AGEN	980 519.41	0.026	10	18
18040 K	AGEN	980 519.38	0.029	8	0
18040 P	BERGERAC	980 568.55	0.029	2	2
18041 J	MONTAUBAN	980 491.54	0.027	0	4
18048 D	SAVONA	980 565.66	0.024	0	5
18049 B	LA SPEZIA	980 555.12	0.022	6	3
18049 J	VALPIANO	980 375.85	0.019	20	21
18049 L	DEPOSITO A.N.A.S	980 408.86	0.019	33	9
18049 N	MIGNEGNO	980 437.66	0.019	43	0
18049 P	MIGLIARINA	980 470.51	0.018	43	0
18049 R	PIASTRA	980 506.16	0.017	29	36
18050 J	MONTIGNAC-LE-COQ	980 604.56	0.026	2	18
18050 P	ANGOULEME	980 647.77	0.029	2	2
18059 A	MILAN	980 550.18	0.017	40	14
18059 B	MILAN	980 549.64	0.017	27	12
18059 J	MILAN	980 548.92	0.017	30	30
18059 K	MILAN	980 549.00	0.021	8	0
18059 L	MILAN	980 543.12	0.031	2	0
18059 M	MILAN	980 544.04	0.019	18	0
18059 N	MILAN	980 543.95	0.024	5	3
18060 J	POITIERS	980 718.20	0.025	10	2
18060 K	POITIERS	980 726.83	0.024	8	16
18060 P	CHATELLERAULT	980 767.13	0.026	2	2
18066 A	GENEVA	980 566.22	0.043	7	0
18066 B	GENEVA	980 565.08	0.040	10	2
18066 C	GENEVA	980 574.61	0.045	5	0
18066 D	GENEVA	980 554.30	0.039	4	2
18066 J	GENEVA	980 574.44	0.045	6	0
18070 J	CHATEAU RENAULT	980 818.59	0.022	8	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
18070 K	CHATEAU RENAULT	980 818.53	0.021	8	16
18078 A	ZURICH	980 652.13	0.035	7	0
18078 B	ZURICH	980 649.96	0.047	2	0
18078 J	ZURICH	980 672.18	0.034	3	3
18078 Q	GEBENSDORF	980 704.71	0.033	2	4
18081 J	CHARTRES	980 871.60	0.020	0	4
18082 A	PARIS	980 925.97	0.014	23	6
18082 B	PARIS	980 928.65	0.020	5	0
18082 C	PARIS	980 929.02	0.017	11	0
18082 E	PARIS	980 928.29	0.020	3	8
18082 J	PARIS	980 935.34	0.017	10	11
18082 K	PARIS	980 935.33	0.017	12	2
18082 M	PARIS	980 899.89	0.027	3	0
18082 N	PARIS	980 901.01	0.019	6	14
18082 O	PARIS	980 898.44	0.015	10	24
18082 P	PARIS	980 899.83	0.015	11	22
18089 J	STUTTGART	980 632.87	0.070	0	2
18091 C	ROUEN	980 994.70	0.097	2	1
18091 J	ROUEN	981 000.79	0.094	6	0
18091 P	ROUEN	981 001.57	0.094	4	4
18098 A	DARMSTADT	981 028.13	0.023	2	3
18098 C	KARLSRUHE	980 942.00	0.024	2	4
18110 A	TEDDINGTON	981 181.78	0.015	26	85
18110 J	TEDDINGTON	981 185.58	0.014	23	34
18110 K	TEDDINGTON	981 185.93	0.016	11	23
18110 M	TEDDINGTON	981 187.04	0.025	5	5
18110 N	TEDDINGTON	981 185.52	0.018	14	3
18110 O	TEDDINGTON	981 185.51	0.018	13	0
18132 J	MANCHESTER	981 345.57	0.074	0	4
18153 A	EDINBURGH	981 568.97	0.026	9	3
18153 J	EDINBURGH	981 563.51	0.026	2	17
18153 K	EDINBURGH	981 561.13	0.029	8	0
18153 N	EDINBURGH	981 586.92	0.025	17	0
18153 O	EDINBURGH	981 587.86	0.024	16	7
18154 B	GLASGOW	981 580.24	0.047	3	4
18154 H	GLASGOW	981 583.91	0.060	1	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
18154 P	GLASGOW	981 560.67	0.049	1	8
18154 S	GLASGOW	981 584.60	0.059	1	3
18165 J	OBAN	981 627.46	0.066	0	8
18730 J	GOOSE BAY	981 292.81	0.023	24	36
18730 K	GOOSE BAY	981 293.24	0.026	15	5
18730 L	GOOSE BAY	981 302.11	0.026	17	0
18746 J	SCHEFFERVILLE	981 316.92	0.018	58	33
18746 K	SCHEFFERVILLE	981 317.53	0.019	41	28
18746 L	SCHEFFERVILLE	981 319.73	0.020	22	0
18746 M	SCHEFFERVILLE	981 316.48	0.025	8	0
18746 N	SCHEFFERVILLE	981 318.17	0.030	5	0
18746 O	SCHEFFERVILLE	981 318.75	0.042	2	0
18746 R	SCHEFFERVILLE	981 316.76	0.021	22	0
18788 J	FORT CHIMO	981 715.33	0.018	20	41
18788 K	FORT CHIMO	981 716.62	0.020	20	0
19214 A	CALGARY	980 813.55	0.015	36	16
19214 C	CALGARY	980 814.06	0.018	18	0
19214 D	CALGARY	980 814.87	0.018	15	1
19214 J	CALGARY	980 814.25	0.012	84	80
19214 K	CALGARY	980 814.40	0.014	63	14
19214 M	CALGARY	980 814.37	0.024	6	0
19214 N	CALGARY	980 809.58	0.017	30	0
19214 O	CALGARY	980 779.02	0.017	36	0
19214 P	CALGARY	980 762.75	0.017	43	0
19214 Q	CALGARY	980 809.89	0.016	35	0
19214 R	CALGARY	980 774.24	0.017	32	0
19223 A	RED DEER	980 982.55	0.020	5	22
19223 B	RED DEER	980 981.86	0.015	5	8
19233 A	EDMONTON	981 153.09	0.012	169	83
19233 B	EDMONTON	981 153.16	0.015	33	28
19233 C	EDMONTON	981 152.79	0.017	10	0
19233 J	EDMONTON	981 119.43	0.014	34	1
19233 K	EDMONTON	981 158.38	0.012	71	18
19233 M	EDMONTON	981 165.84	0.012	81	92
19233 N	EDMONTON	981 152.81	0.015	36	0
19233 O	EDMONTON	981 158.65	0.013	70	0
19233 P	EDMONTON	981 121.69	0.018	16	0
19233 Q	EDMONTON	981 119.45	0.014	44	21
19233 R	EDMONTON	981 118.01	0.012	64	65

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER		---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
19233	T	EDMONTON	981 117.92	0.013	64	49
19233	V	EDMONTON	981 158.68	0.023	8	0
19233	W	EDMONTON	981 158.50	0.023	9	0
19233	X	EDMONTON	981 163.68	0.019	16	0
19233	Y	EDMONTON	981 151.47	0.015	39	0
19258	A	GRANDE PRAIRIE	981 303.22	0.019	22	14
19258	B	GRANDE PRAIRIE	981 302.85	0.030	2	0
19258	J	GRANDE PRAIRIE	981 300.99	0.020	17	4
19258	K	GRANDE PRAIRIE	981 301.04	0.016	5	38
19258	L	GRANDE PRAIRIE	981 301.11	0.075	0	4
19360	A	FORT ST.JOHN	981 391.21	0.016	26	32
19360	J	FORT ST.JOHN	981 390.78	0.023	3	[illegible]
19360	K	FORT ST.JOHN	981 390.80	0.018	19	2
19360	L	FORT ST.JOHN	981 391.23	0.014	20	56
19382	J	FORT NELSON	981 678.39	0.055	17	7
19382	K	FORT NELSON	981 678.47	0.058	6	0
19382	L	FORT NELSON	981 666.73	0.057	11	0
19816	J	ADAK	981 427.64	0.060	0	4
21500	J	BISCHOFSHEIM	980 992.26	0.017	16	16
21500	L	BAD NEUSTADT	981 031.77	0.017	44	18
21500	N	SAAL A.D. SAALE	981 030.13	0.018	32	0
21500	P	SULZDORF	981 001.51	0.017	45	7
21500	R	PFARRWEISACH	980 995.00	0.017	33	15
21500	T	RECKENDORF	980 99[illegible].39	0.017	12	12
21510	A	BAD HARZBURG	981 165.50	0.014	44	93
21510	B	BAD HARZBURG	981 165.55	0.014	36	44
21510	C	BAD HARZBURG	981 165.25	0.014	38	46
21510	J	BAD HARZBURG	981 174.18	0.019	8	0
21510	G	TORFHAUS	981 080.02	0.022	5	0
21510	H	TORFHAUS	981 081.07	0.015	61	0
21510	P	BRAUNLAGE	981 124.56	0.015	46	2
21510	R	ODERTAL	981 157.36	0.016	44	0
21510	T	HERZBERG	981 169.15	0.017	20	0
21510	V	WOLLBRANDHAUSEN	981 170.35	0.015	26	26
21520	C	BRAUNSCHWEIG	981 251.84	0.014	35	33
21520	D	BRAUNSCHWEIG	981 252.26	0.020	8	0
21520	G	BRAUNSCHWEIG	981 252.05	0.015	1	18
21520	P	PEINE	981 252.83	0.016	9	9
21520	R	WOLFENBUTTEL	981 237.16	0.016	20	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
21520 T	SCHLADEN	981 214.36	0.014	22	22
21520 Y	CELLE	981 291.02	0.015	0	20
21521 J	HELMSTEDT	981 254.24	0.015	0	54
21523 A	POTSDAM	981 260.19	0.017	21	2
21523 B	POTSDAM	981 260.70	0.016	31	10
21523 F	POTSDAM	981 261.21	0.017	23	4
21523 G	POTSDAM	981 261.39	0.017	25	4
21523 J	POTSDAM	981 266.73	0.028	1	6
21523 L	POTSDAM	981 257.09	0.022	5	5
21523 V	BURG	981 254.07	0.015	12	12
21523 W	BRANDENBURG	981 253.48	0.015	30	6
21530 J	GESCHENDORF-STEINBEK	981 402.05	0.016	10	10
21530 L	STOCKELDORF-FACKENBURG	981 401.81	0.016	20	14
21530 P	SCHMALENBECK	981 375.15	0.016	10	10
21530 R	RETHWISCHDORF WEST	981 384.02	0.018	18	0
21540 J	RICKLING	981 420.39	0.016	0	20
21550 J	NYBORG	981 541.61	0.017	17	23
21550 N	HJULBY	981 539.38	0.017	17	11
21550 P	EIBY	981 553.51	0.016	28	32
21551 J	RINGSTED	981 524.32	0.015	30	48
21551 M	VEMMELEV	981 532.54	0.016	17	11
21551 P	KORSOR	981 533.54	0.016	19	19
21552 A	COPENHAGEN	981 543.02	0.015	22	6
21552 B	COPENHAGEN	981 543.19	0.016	16	17
21552 C	COPENHAGEN	981 542.56	0.014	44	64
21552 H	COPENHAGEN	981 542.57	0.029	1	4
21552 J	COPENHAGEN	981 542.75	0.017	6	20
21552 K	COPENHAGEN	981 542.44	0.014	29	73
21552 L	COPENHAGEN	981 542.26	0.014	16	31
21552 R	ROSKILDE	981 544.03	0.019	4	4
21552 T	NYBO	981 560.67	0.029	2	1
21552 U	NYBO	981 560.13	0.018	8	7
21552 V	ROSKILDE	981 544.20	0.016	6	6
21562 J	HELSINGBORG	981 609.86	0.015	27	39
21562 K	HELSINGBORG	981 610.08	0.020	8	0
21562 L	HELSINGBORG	981 609.70	0.021	5	3
21562 Q	HELLEBAEK	981 590.05	0.024	4	0
21562 T	HELSINGOR	981 577.07	0.015	22	42

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
21563 J	VEINGE KE.	981 656.35	0.017	0	38
21571 J	S.KRISTINA KE.	981 727.10	0.018	0	48
21572 J	APELVIKSAAS	981 701.94	0.017	8	28
21572 K	APELVIKSAAS	981 696.34	0.017	10	34
21572 L	APELVIKSAAS	981 694.89	0.023	2	6
21581 J	HOGSTORP	981 755.60	0.018	8	27
21581 K	HOGSTORP	981 752.95	0.018	24	14
21581 L	HOGSTORP	981 752.21	0.023	4	4
21581 P	TANUM	981 785.66	0.029	3	2
21581 Q	TANUM	981 786.24	0.018	15	28
21581 T	OSTAD	981 781.86	0.035	2	0
21590 A	OSLO	981 912.61	0.016	61	35
21590 B	OSLO	981 914.12	0.017	33	25
21590 J	OSLO	981 916.20	0.018	15	0
21590 K	OSLO	981 916.10	0.015	43	59
21590 L	OSLO	981 916.34	0.019	5	0
21590 N	OSLO	981 917.68	0.022	6	0
21590 O	OSLO	981 917.15	0.016	35	26
21590 S	OSLO	981 917.14	0.019	6	14
21590 T	SONSVEIEN	981 886.24	0.018	14	17
21590 X	TRYVASSHOGDA	981 804.09	0.021	8	0
21590 Y	HOLMENKOLLEN	981 859.21	0.020	10	0
21591 J	SVINESUNDE	981 825.61	0.017	8	27
21591 K	SVINESUNDE	981 837.34	0.018	17	20
21591 L	SVINESUNDE	981 837.71	0.026	1	4
21591 P	SALE KE.	981 857.64	0.019	8	8
21597 A	STOCKHOLM	981 831.43	0.067	7	0
21597 C	STOCKHOLM	981 831.10	0.068	4	0
21597 E	STOCKHOLM	981 827.96	0.071	2	0
21597 J	STOCKHOLM	981 830.66	0.066	3	2
21597 K	STOCKHOLM	981 830.91	0.065	4	2
21604 A	BRUSSELS	981 117.32	0.032	7	0
21604 B	BRUSSELS	981 116.77	0.035	4	0
21604 C	BRUSSELS	981 127.12	0.045	2	0
21604 J	BRUSSELS	981 146.76	0.028	7	1
21604 K	BRUSSELS	981 145.06	0.036	2	5
21604 L	BRUSSELS	981 141.25	0.023	2	5
21604 S	BRUSSELS	981 141.20	0.032	4	5
21608 A	FRANKFURT	981 046.32	0.018	17	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
21608 B	FRANKFURT	981 046.15	0.019	11	3
21608 J	FRANKFURT	981 042.43	0.017	3	37
21608 K	FRANKFURT	981 042.79	0.016	33	5
21608 L	FRANKFURT	981 042.45	0.023	4	0
21608 M	FRANKFURT	981 042.50	0.019	8	0
21608 O	FRANKFURT	981 042.44	0.013	20	39
21608 P	FRANKFURT	981 042.00	0.012	8	41
21609 J	BAD HERSFELD	981 104.53	0.014	40	28
21609 K	BAD HERSFELD	981 106.53	0.019	8	0
21609 N	AUA	981 086.50	0.015	10	10
21609 P	NEUKIRCHEN	981 086.21	0.015	46	12
21609 R	HUNFELD	981 069.34	0.017	20	0
21609 T	FULDA	981 062.09	0.016	51	18
21609 V	SCHMALNAU	981 027.03	0.017	23	22
21616 J	DUSSELDORF	981 [illegible]84.48	0.048	0	5
21619 B	GOTTINGEN OST	981 141.96	0.015	15	17
21619 C	GOTTINGEN	981 163.40	0.016	13	13
21619 P	HEDEMUNDEN	981 158.63	0.016	20	0
21619 R	KASSEL OST	981 153.73	0.014	54	22
21619 V	MELSUNGEN-BEUERN	981 100.47	0.015	28	24
21625 J	AMSTERDAM	981 273.40	0.048	1	2
21625 K	AMSTERDAM	981 273.35	0.050	1	4
21629 A	HANOVER	981 262.37	0.014	28	20
21629 B	HANOVER	981 262.04	0.014	26	15
21629 J	HANOVER	981 272.50	0.014	60	8
21629 K	HANOVER	981 272.62	0.015	13	28
21629 L	HANOVER	981 272.63	0.019	8	0
21629 M	HANOVER	981 272.62	0.014	30	18
21629 R	SOLTAU	981 302.94	0.014	26	46
21629 T	BERGEN	981 287.90	0.019	4	4
21629 U	BERGEN	981 287.89	0.015	6	6
21629 V	SCHILLERSLAL	981 275.22	0.014	21	21
21629 X	LEHRTE	981 257.78	0.016	10	10
21638 J	BREMEN	981 320.35	0.021	8	4
21638 K	BREMEN	981 321.48	0.017	8	16
21639 A	HAMBURG	981 363.60	0.018	9	0
21639 B	HAMBURG	981 363.78	0.014	58	39
21639 C	HAMBURG	981 374.94	0.016	14	10
21639 D	HAMBURG	981 379.53	0.015	28	27

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
21639 J	HAMBURG	981 379.69	0.016	22	0
21639 K	HAMBURG	981 379.63	0.016	17	18
21639 L	HAMBURG	981 378.93	0.021	5	0
21639 M	HAMBURG	981 379.50	0.015	32	18
21639 P	HAMBURG	981 378.66	0.015	15	29
21639 T	STEINBECK	981 343.80	0.016	26	0
21639 V	BARRL	981 322.08	0.020	4	4
21639 W	BARRL	981 321.88	0.014	12	12
21649 B	FLENSBURG	981 485.68	0.016	48	15
21649 E	RENDSBURG	981 443.48	0.017	18	3
21649 F	RENDSBURG	981 443.37	0.015	79	30
21649 G	RENDSBURG	981 445.52	0.020	8	0
21649 J	KRUSAA	981 490.14	0.016	33	15
21649 M	SOGARD	981 514.63	0.016	10	14
21649 P	POPPHOLZ	981 479.00	0.018	20	0
21649 R	JAGEL	981 466.17	0.017	20	0
21649 T	BRAMMER	981 428.08	0.019	7	1
21649 U	BRAMMER	981 428.42	0.018	12	0
21649 V	NEUMUNSTER-NORD	981 413.84	0.015	25	25
21659 J	MIDDELFART	981 564.22	0.016	29	41
21659 M	CHRISTIANSFELD	981 559.42	0.017	29	1
21659 P	HOPTRUP	981 550.65	0.016	28	40
21716 P	TVERAA	982 052.05	0.049	0	6
21726 C	TORSHAVN	982 087.05	0.050	10	0
21726 D	TORSHAVN	982 085.95	0.051	9	0
21726 F	TORSHAVN	982 090.12	0.052	8	0
21726 P	TORSHAVN	982 093.57	0.049	6	3
21726 Q	TORSHAVN	982 103.91	0.052	3	3
21941 A	REYKJAVIK	982 264.96	0.022	32	0
21941 B	REYKJAVIK	982 258.79	0.024	17	8
21941 C	REYKJAVIK	982 262.46	0.028	12	0
21941 D	REYKJAVIK	982 264.82	0.033	6	0
21941 J	REYKJAVIK	982 266.34	0.025	11	0
21941 K	REYKJAVIK	982 259.43	0.018	21	24
21941 L	REYKJAVIK	982 263.33	0.019	29	7
21941 M	REYKJAVIK	982 259.33	0.061	1	4
21941 O	REYKJAVIK	982 196.85	0.026	6	0
21941 P	REYKJAVIK	982 266.06	0.033	6	6
21941 Q	REYKJAVIK	982 265.77	0.030	5	0
22270 J	SONDRESTROMFJORD	982 370.11	0.038	15	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	TIMES TIED EXT
22270 K	SONDRESTROMFJORD	982 370.04	0.038	14	2
22270 L	SONDRESTROMFJORD	982 375.04	0.042	4	0
22270 M	SONDRESTROMFJORD	982 368.47	0.037	9	9
22338 J	FROBISHER BAY	982 151.71	0.017	27	68
22338 K	FROBISHER BAY	982 150.37	0.019	16	0
22338 L	FROBISHER BAY	982 153.36	0.031	4	0
22338 N	FROBISHER BAY	982 153.80	0.026	7	0
22361 J	CAPE DYER	982 304.05	0.039	0	13
22485 J	LONGSTAFF	982 492.38	0.043	0	8
22581 J	HALL BEACH	982 489.14	0.021	20	49
22581 K	HALL BEACH	982 488.68	0.023	20	0
22908 A	WATSON LAKE	981 700.39	0.094	13	3
22908 J	WATSON LAKE	981 699.98	0.096	6	0
22908 K	WATSON LAKE	981 695.27	0.096	6	0
22908 L	WATSON LAKE	981 699.88	0.025	1	11
23005 A	WHITEHORSE	981 735.49	0.013	68	234
23005 B	WHITEHORSE	981 734.25	0.017	20	12
23005 D	WHITEHORSE	981 747.90	0.018	8	0
23005 E	WHITEHORSE	981 735.40	0.017	8	4
23005 J	WHITEHORSE	981 734.25	0.014	53	0
23005 K	WHITEHORSE	981 734.11	0.022	6	1
23005 L	WHITEHORSE	981 734.32	0.015	27	0
23005 M	WHITEHORSE	981 735.70	0.015	38	6
23005 N	WHITEHORSE	981 747.87	0.020	12	0
23119 A	ANCHORAGE	981 925.19	0.016	31	0
23119 J	ANCHORAGE	981 923.56	0.015	38	15
23119 K	ANCHORAGE	981 905.86	0.016	14	35
23119 N	ANCHORAGE	981 905.84	0.016	23	12
23119 O	ANCHORAGE	981 905.97	0.017	16	20
23147 A	FAIRBANKS	982 231.71	0.014	145	88
23147 B	FAIRBANKS	982 229.91	0.015	64	6
23147 C	FAIRBANKS	982 231.70	0.015	27	0
23147 E	FAIRBANKS	982 235.00	0.014	40	18
23147 J	FAIRBANKS	982 229.37	0.021	6	0
23147 K	FAIRBANKS	982 231.97	0.014	149	115
23147 M	FAIRBANKS	982 203.51	0.014	120	57
23147 N	FAIRBANKS	982 203.16	0.014	45	95
23147 O	FAIRBANKS	982 232.05	0.020	8	6

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	TIMES TIED EXT
25004 A	HELSINKI	981 900.59	0.019	36	54
25004 O	HELSINKI	981 964.58	0.024	5	0
25004 S	HELSINKI	981 910.09	0.018	39	27
25004 T	HELSINKI	981 910.17	0.020	24	0
25004 U	HELSINKI	981 909.06	0.020	24	0
25045 J	OULU	982 236.28	0.040	0	12
25065 J	ROVANIEMI	982 320.45	0.042	0	8
25087 J	IVALO	982 496.84	0.042	0	11
25090 J	SORKJOSEN	982 510.05	0.038	0	6
25093 J	ALTA	982 529.84	0.028	20	18
25093 K	ALTA	982 534.28	0.028	12	8
25093 L	ALTA	982 533.71	0.030	18	0
25093 M	ALTA	982 534.45	0.032	8	4
25093 N	ALTA	982 529.89	0.040	2	0
25101 K	HAMAR	981 913.31	0.020	14	24
25101 N	TANGEN	981 904.26	0.019	28	0
25101 P	JESSHEIM	981 891.36	0.018	14	14
25110 J	ROGNDALSVEEN	981 900.66	0.021	8	8
25110 P	LILLEHAMMER	981 899.08	0.020	8	37
25120 J	SOKNEDAL	982 066.52	0.019	8	36
25120 K	SOKNEDAL	982 062.68	0.019	8	27
25130 A	TRONDHEIM	982 146.74	0.018	54	12
25130 C	TRONDHEIM	982 146.59	0.018	60	10
25130 J	TRONDHEIM	982 138.54	0.018	31	1
25130 K	TRONDHEIM	982 137.79	0.019	62	4
25130 L	TRONDHEIM	982 138.59	0.017	77	65
25130 M	TRONDHEIM-STJORDAL	982 141.75	0.018	35	14
25130 N	TRONDHEIM	982 138.43	0.021	12	0
25130 T	STOREN	982 117.93	0.018	19	18
25131 K	MAERE	982 173.43	0.020	13	35
25131 P	SKOGN	982 161.40	0.020	13	13
25142 J	LANGHAUGEN	982 197.49	0.023	6	6
25142 R	FORMOFOSS	982 178.30	0.022	17	19
25142 T	LANGNESS	982 181.65	0.022	11	11
25143 J	VEISKILLE	982 197.86	0.022	0	36

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
25153 J	MAJAVATN	982 203.34	0.022	19	11
25153 K	MAJAVATN	982 202.17	0.021	14	22
25153 P	FELLINGFORS	982 249.49	0.022	34	4
25153 R	MOSJOEN	982 292.27	0.023	27	5
25153 T	SOVARNES	982 277.86	0.023	12	16
25163 J	SKAMDAL	982 303.45	0.024	0	25
25164 J	MO-I-RANA	982 309.74	0.024	8	12
25164 K	MO-I-RANA	982 308.94	0.023	8	16
25165 K	LEIRJORDFALL	982 268.79	0.022	18	19
25165 N	LONSDAL	982 164.05	0.028	6	6
25165 P	VISKISKOJA	982 197.28	0.027	12	0
25165 R	KROKSTRAND	982 233.10	0.023	12	18
25165 U	STORJORD	982 240.57	0.026	12	0
25174 A	BODO	982 372.65	0.021	27	22
25174 B	BODO	982 371.84	0.022	19	11
25174 J	BODO	982 372.97	0.020	30	59
25174 K	BODO	982 375.56	0.021	19	9
25174 R	BODO	982 375.53	0.040	1	1
25175 J	FAUSKE	982 322.96	0.022	3	53
25175 N	INNHAVET	982 384.13	0.028	3	3
25187 J	NARVIK	982 437.23	0.026	14	6
25187 K	NARVIK	982 436.99	0.025	8	15
25187 R	FOSSBAKKEN	982 419.96	0.028	6	6
25198 K	BARDUFOSS	982 476.50	0.031	0	12
25199 J	TROMSO	982 552.46	0.027	19	25
25199 K	TROMSO	982 557.11	0.029	16	0
25199 L	TROMSO	982 556.94	0.029	11	3
25199 M	TROMSO	982 552.74	0.030	8	0
25219 J	BRENNHAUG	981 886.30	0.020	14	12
25219 Q	VINSTRA	981 904.76	0.020	14	41
25229 K	OPPDAL	981 950.79	0.019	32	0
25229 L	OPPDAL	981 950.61	0.019	20	21
25229 P	LUNDHEIM	982 007.98	0.019	18	13
25229 R	HESTEHAGEN	981 883.34	0.019	36	0
25229 U	HJERKINN	981 844.77	0.020	18	28
25968 J	THULE	982 913.75	0.027	18	1

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
25968 K	THULE	982 914.29	0.026	18	61
26195 J	EUREKA	983 014.09	0.028	14	0
26195 K	EUREKA	982 998.26	0.026	14	25
26244 J	RESOLUTE BAY	982 848.76	0.028	31	3
26244 K	RESOLUTE BAY	982 848.75	0.027	25	28
26244 L	RESOLUTE BAY	982 848.74	0.028	27	4
26244 M	RESOLUTE BAY	982 849.20	0.032	5	4
26244 N	RESOLUTE BAY	982 848.79	0.035	6	0
26469 J	MOULD BAY	982 922.51	0.046	6	1
26469 K	MOULD BAY	982 912.98	0.044	13	0
26469 L	MOULD BAY	982 921.70	0.043	16	0
26469 O	MOULD BAY	982 920.99	0.041	19	13
26469 P	MOULD BAY	982 922.51	0.059	2	0
26703 J	BARTER ISLAND	982 581.56	0.043	0	10
26816 A	POINT BARROW	982 685.18	0.017	53	107
26816 B	POINT BARROW	982 685.00	0.018	27	3
26816 K	POINT BARROW	982 685.21	0.021	11	0
26816 L	POINT BARROW	982 685.13	0.020	17	3
26816 M	POINT BARROW	982 683.17	0.020	12	8
28603 A	HAMMERFEST	982 617.62	0.027	17	48
28603 B	HAMMERFEST	982 618.53	0.029	19	3
28603 J	HAMMERFEST	982 615.48	0.031	8	0
29522 J	ALERT	983 129.92	0.031	23	11
29522 K	ALERT	983 119.82	0.033	20	0
29522 L	ALERT	983 119.13	0.033	19	0
29522 M	ALERT	983 117.96	0.032	18	4
29522 O	ALERT	983 132.48	0.040	4	0
32674 B	ASCENSION ISLAND	978 289.39	0.028	12	0
32674 J	ASCENSION ISLAND	978 279.39	0.025	12	26
32674 K	ASCENSION ISLAND	978 279.39	0.028	12	0
32838 J	FORTALEZA	978 067.81	0.026	7	16
32838 K	FORTALEZA	978 066.94	0.028	7	5
32875 J	JOAO PESSOA	978 129.03	0.029	0	6
32884 J	RECIFE	978 151.25	0.024	16	17
32884 K	RECIFE	978 153.07	0.025	10	11

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
32884 L	RECIFE	978 151.27	0.023	11	21
32884 M	RECIFE	978 162.52	0.029	5	0
32918 A	BELEM	978 022.24	0.028	24	2
32918 K	BELEM	978 018.97	0.030	12	0
32918 L	BELEM	978 019.08	0.027	25	30
32918 N	BELEM	978 024.63	0.034	7	0
32918 O	BELEM	978 024.59	0.031	16	0
32977 J	CAROLINA	978 031.11	0.038	0	8
33039 J	MANAUS	978 006.16	0.037	0	8
33134 J	TEFE	978 031.88	0.040	0	8
33208 A	QUITO	977 263.19	0.029	23	18
33208 J	QUITO	977 271.44	0.031	7	2
33208 K	QUITO	977 270.38	0.028	24	37
33229 K	GUAYAQUIL	978 129.34	0.023	20	35
33229 L	GUAYAQUIL	978 129.68	0.027	8	0
33229 M	GUAYAQUIL	978 123.71	0.025	12	7
33229 N	GUAYAQUIL	978 076.30	0.031	4	0
33229 P	GUAYAQUIL	978 104.95	0.030	4	0
33233 J	IQUITOS	978 072.11	0.036	0	8
33341 K	TALARA	978 118.65	0.024	14	26
33341 L	TALARA	978 118.60	0.026	14	0
34221 J	CANTON ISLAND	978 278.80	0.102	3	1
34221 K	CANTON ISLAND	978 295.17	0.102	3	1
34697 J	PORT MORESBY	978 198.33	0.065	0	2
35704 J	KISUMU	977 591.34	0.054	0	2
35716 A	NAIROBI	977 526.07	0.026	55	46
35716 B	NAIROBI	977 518.65	0.029	10	0
35716 C	NAIROBI	977 513.75	0.038	2	0
35716 J	NAIROBI	977 528.77	0.029	7	9
35716 K	NAIROBI	977 521.51	0.027	24	0
35716 M	NAIROBI	977 519.81	0.033	3	0
35716 N	NAIROBI	977 540.40	0.026	58	27
35716 O	NAIROBI	977 540.46	0.026	30	12
35716 P	NAIROBI	977 540.27	0.026	33	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	TIMES TIED EXT
35716 Q	NAIROBI	977 540.39	0.025	26	38
35737 J	MOSHI	977 761.38	0.031	8	0
35737 K	MOSHI	977 757.88	0.028	8	15
35752 J	TABORA	977 669.95	0.062	0	2
35769 J	DAR ES SALAAM	978 104.90	0.032	8	0
35769 K	DAR ES SALAAM	978 100.11	0.030	8	24
35781 J	ABERCORN	977 656.62	0.070	0	2
35783 J	MBEYA	977 659.81	0.039	8	0
35783 K	MBEYA	977 669.89	0.036	8	8
35828 J	BUKAVU(COSTERMANSVILLE)	977 569.15	0.072	0	2
35839 J	BUJUMBURA(USUMBURA)	977 716.27	0.062	0	2
35941 J	POINTE NOIRE	978 013.28	0.043	0	4
35945 A	KINSHASA(LEOPOLDVILLE)	977 8[illegible]9.82	0.028	25	4
35945 J	KINSHASA(LEOPOLDVILLE)	977 937.13	0.032	5	1
35945 K	KINSHASA(LEOPOLDVILLE)	977 937.80	0.030	11	0
35945 L	KINSHASA(LEOPOLDVILLE)	977 928.32	0.028	16	0
35945 M	KINSHASA(LEOPOLDVILLE)	977 928.20	0.026	13	48
35945 R	KINSHASA(LEOPOLDVILLE)	977 927.67	0.033	2	7
35983 B	LUANDA	978 195.74	0.034	8	0
35983 J	LUANDA	978 179.71	0.031	9	16
35983 K	LUANDA	978 179.74	0.058	1	5
36428 B	SALVADOR	978 311.31	0.030	7	0
36428 J	SALVADOR	978 329.43	0.027	7	16
36428 K	SALVADOR	978 329.52	0.038	4	4
36428 M	SALVADOR	978 302.91	0.042	4	0
36479 B	CARAVELAS	978 511.14	0.030	7	0
36479 J	CARAVELAS	978 511.46	0.027	7	15
36508 J	PORTO NACIONAL	978 145.44	0.040	0	8
36557 J	BRAZILIA	978 084.92	0.039	4	8
36557 K	BRAZILIA	978 086.07	0.043	4	0
36557 L	BRAZILIA	978 084.69	0.087	0	4
36569 J	GOIANIA	978 225.40	0.040	0	8

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
36593 J	BELO HORIZONTE	978 365.50	0.031	0	8
36768 A	LA PAZ	977 452.19	0.027	38	20
36768 B	LA PAZ	977 452.89	0.028	20	16
36768 J	LA PAZ	977 334.22	0.028	16	11
36768 K	LA PAZ	977 338.00	0.028	16	4
36768 L	LA PAZ	977 334.02	0.028	18	8
36773 J	SANTA CRUZ	978 349.44	0.040	4	4
36773 K	SANTA CRUZ	978 349.07	0.044	4	0
36827 A	LIMA	978 267.94	0.021	55	2
36827 B	LIMA	978 267.34	0.022	18	16
36827 C	LIMA	978 264.84	0.023	12	1
36827 D	LIMA	978 257.33	0.024	7	0
36827 J	LIMA	978 264.08	0.022	20	8
36827 K	LIMA	978 292.18	0.020	57	81
36827 L	LIMA	978 292.08	0.020	50	20
36827 M	LIMA	978 297.79	0.027	4	0
36827 N	LIMA	978 292.27	0.023	12	0
36827 O	LIMA	978 292.37	0.022	15	0
36861 K	AREQUIPA	977 701.73	0.027	7	16
36861 L	AREQUIPA	977 701.70	0.028	7	8
36880 K	ARICA	978 480.06	0.024	7	17
36880 L	ARICA	978 478.54	0.025	11	14
36880 M	ARICA	978 515.53	0.032	4	0
36880 N	ARICA	978 495.82	0.032	4	0
37579 A	TAHITI	978 629.57	0.058	6	0
37579 B	TAHITI	978 696.83	0.056	17	1
37579 C	TAHITI	978 687.65	0.059	4	0
37579 D	TAHITI	978 691.92	0.059	4	0
37579 J	TAHITI	978 693.53	0.057	7	3
37579 K	TAHITI	978 696.53	0.056	7	3
37579 L	TAHITI	978 703.28	0.064	2	0
37579 M	TAHITI	978 708.54	0.067	2	0
37579 N	TAHITI	978 715.93	0.064	2	0
37579 P	TAHITI	978 698.93	0.058	3	1
37841 J	PAGO PAGO	978 625.55	0.064	7	6
37841 K	PAGO PAGO	978 642.46	0.065	7	0
37841 L	PAGO PAGO	978 626.16	0.036	0	8
37977 J	NANDI-FIJI ISLAND	978 532.81	0.024	2	24

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
37977 K	NANDI-FIJI ISLAND	978 480.77	0.036	2	0
38265 A	CAIRNS	978 486.24	0.037	17	18
38265 K	CAIRNS	978 482.02	0.039	15	0
38265 L	CAIRNS	978 484.71	0.038	30	0
38296 A	TOWNSVILLE	978 609.74	0.035	27	0
38296 B	TOWNSVILLE	978 610.43	0.037	11	4
38296 C	TOWNSVILLE	978 609.69	0.035	10	1
38296 L	TOWNSVILLE	978 612.85	0.035	31	0
38296 M	TOWNSVILLE	978 552.30	0.037	16	0
38296 N	TOWNSVILLE	978 609.66	0.034	37	24
38320 A	DARWIN	978 299.55	0.030	29	22
38320 B	DARWIN	978 301.32	0.029	31	0
38320 J	DARWIN	978 300.93	0.028	18	20
38320 K	DARWIN	978 300.93	0.032	3	6
38320 L	DARWIN	978 300.51	0.030	4	0
38320 M	DARWIN	978 302.59	0.032	10	0
38320 N	DARWIN	978 299.54	0.045	2	0
38320 P	DARWIN	978 300.87	0.040	6	0
38320 Q	DARWIN	978 300.84	0.035	6	0
38320 R	DARWIN	978 300.86	0.044	3	2
38726 J	COCOS ISLAND	978 454.54	0.078	0	4
39297 J	TANANARIVE	978 202.42	0.046	0	4
39301 J	KASAMA	977 773.54	0.063	0	2
39355 J	BLANTYRE	978 202.52	0.043	0	2
39371 A	SALISBURY	978 133.65	0.035	9	8
39371 B	SALISBURY	978 113.45	0.033	16	0
39371 J	SALISBURY	978 134.14	0.034	8	0
39371 K	SALISBURY	978 108.41	0.043	2	0
39371 L	SALISBURY	978 111.05	0.034	9	0
39371 M	SALISBURY	978 111.00	0.031	16	15
39417 J	LUBUMBASHI(ELISABETHVILLE)	977 875.34	0.054	0	2
39428 J	NDOLA	977 896.90	0.036	8	0
39428 K	NDOLA	977 898.30	0.032	8	15
39428 L	NDOLA	977 898.20	0.035	8	0
39428 M	NDOLA	977 898.36	0.035	8	2
39458 A	LUSAKA	978 039.29	0.035	8	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
39458 J	LUSAKA	978 039.32	0.032	8	15
39458 K	LUSAKA	978 038.20	0.035	8	0
39475 K	VICTORIA FALLS	978 205.70	0.028	8	16
39475 L	VICTORIA FALLS	978 213.56	0.031	8	0
39475 M	VICTORIA FALLS	978 205.66	0.047	0	4
39525 B	NOVA LISBOA	977 811.86	0.039	8	0
39525 J	NOVA LISBOA	977 814.96	0.037	8	16
39543 B	SA DA BANDEIRA	977 910.93	0.041	8	0
39543 J	SA DA BANDEIRA	977 917.03	0.039	8	8
40100 B	VITORIA	978 641.83	0.030	6	0
40100 J	VITORIA	978 638.25	0.026	7	16
40100 K	VITORIA	978 638.38	0.034	1	4
40111 B	CAMPOS	978 721.16	0.028	7	0
40111 J	CAMPOS	978 717.49	0.025	7	16
40123 A	RIO DE JANEIRO	978 789.90	0.019	55	39
40123 J	RIO DE JANEIRO	978 783.05	0.021	14	3
40123 K	RIO DE JANEIRO	978 782.93	0.020	28	34
40123 L	RIO DE JANEIRO	978 793.55	0.019	53	10
40123 M	RIO DE JANEIRO	978 637.28	0.027	4	0
40123 O	RIO DE JANEIRO	978 792.78	0.026	4	0
40136 J	SAO PAULO	978 627.29	0.026	1	16
40136 M	SAO PAULO	978 635.56	0.025	1	15
40178 A	FLORIANOPOLIS	979 112.39	0.030	6	0
40178 J	FLORIANOPOLIS	979 118.93	0.026	6	16
40257 B	ASUNCION	978 949.23	0.026	6	0
40257 J	ASUNCION	978 943.12	0.022	6	25
40334 K	ORAN	978 623.48	0.037	0	14
40345 K	SALTA	978 483.95	0.036	0	32
40365 J	TUCUMAN	978 892.21	0.040	1	8
40365 K	TUCUMAN	978 892.06	0.034	4	14
40365 L	TUCUMAN	978 892.08	0.033	5	14
40374 K	SANTIAGO DEL ESTERO	979 084.35	0.030	0	28
40400 K	IQUIQUE	978 664.01	0.024	8	28

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
40400 L	IQUIQUE	978 665.50	0.028	8	0
40420 K	TOCOPILLA	978 595.15	0.025	0	26
40430 A	ANTOFAGASTA	978 889.52	0.024	30	0
40430 B	ANTOFAGASTA	978 889.92	0.033	3	0
40430 C	ANTOFAGASTA	978 891.43	0.034	3	0
40430 J	ANTOFAGASTA	978 870.38	0.026	8	6
40430 K	ANTOFAGASTA	978 870.30	0.023	37	35
40430 L	ANTOFAGASTA	978 868.04	0.029	5	0
40430 M	ANTOFAGASTA	978 893.20	0.026	8	0
41730 A	ROCKHAMPTON	978 856.06	0.033	10	0
41730 J	ROCKHAMPTON	978 859.35	0.031	24	0
41730 K	ROCKHAMPTON	978 860.04	0.029	14	28
41752 A	MARYBOROUGH	979 007.32	0.027	14	24
41752 J	MARYBOROUGH	979 009.10	0.029	14	0
41773 A	BRISBANE	979 155.93	0.033	4	0
41773 B	BRISBANE	979 155.16	0.029	5	16
41773 C	BRISBANE	979 155.95	0.026	22	0
41773 D	BRISBANE	979 155.34	0.026	41	2
41773 J	BRISBANE	979 145.57	0.025	28	42
41773 K	BRISBANE	979 154.11	0.029	11	0
41773 N	BRISBANE	979 097.09	0.027	30	0
41773 O	BRISBANE	979 097.66	0.035	3	0
41792 J	GRAFTON	979 306.36	0.028	10	0
41792 K	GRAFTON	979 315.37	0.026	10	18
41819 A	MACKAY	978 720.77	0.033	14	0
41819 J	MACKAY	978 719.88	0.032	14	27
41909 J	MT.ISA	978 604.41	0.027	0	18
41933 J	ALICE SPRINGS	978 639.39	0.044	4	8
41933 K	ALICE SPRINGS	978 639.66	0.048	8	0
41933 L	ALICE SPRINGS	978 626.67	0.051	10	0
41933 M	ALICE SPRINGS	978 678.83	0.052	6	0
42707 J	MAURITIUS ISLAND	978 852.21	0.032	10	17
42707 O	MAURITIUS ISLAND	978 911.57	0.034	17	0
42707 P	MAURITIUS ISLAND	978 911.30	0.050	2	0
42707 Q	MAURITIUS ISLAND	978 908.68	0.036	8	0
42952 J	LOURENCO MARQUES	979 037.98	0.055	0	2

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
42961 B	MBABANE	978 700.22	0.035	0	6
43008 A	BULAWAYO	978 276.32	0.029	8	0
43008 J	BULAWAYO	978 277.54	0.029	8	0
43008 K	BULAWAYO	978 266.95	0.025	8	16
43039 J	PIETERSBURG	978 503.94	0.031	8	0
43039 K	PIETERSBURG	978 503.69	0.028	8	8
43055 B	LOBATSI	978 620.60	0.041	0	2
43058 A	PRETORIA	978 615.30	0.021	8	36
43058 B	PRETORIA	978 615.10	0.024	8	0
43068 A	JOHANNESBURG	978 535.46	0.020	62	83
43068 K	JOHANNESBURG	978 536.10	0.021	29	2
43068 L	JOHANNESBURG	978 536.05	0.019	86	84
43068 M	JOHANNESBURG	978 536.57	0.020	31	46
43084 A	KIMBERLEY	978 857.67	0.032	8	0
43084 B	KIMBERLEY	978 857.66	0.030	8	0
43084 J	KIMBERLEY	978 873.71	0.030	8	0
43084 K	KIMBERLEY	978 873.19	0.026	8	16
43801 B	PORTO ALEGRE	979 305.00	0.029	8	0
43801 J	PORTO ALEGRE	979 300.78	0.026	8	16
43812 B	PELOTAS	979 466.63	0.028	6	0
43812 J	PELOTAS	979 462.60	0.024	6	16
43846 J	MONTEVIDEO	979 745.16	0.035	5	2
43846 K	MONTEVIDEO	979 731.56	0.031	5	6
43848 A	BUENOS AIRES	979 690.03	0.018	60	18
43848 C	BUENOS AIRES	979 691.16	0.020	15	0
43848 D	BUENOS AIRES	979 736.85	0.025	5	0
43848 J	BUENOS AIRES	979 718.05	0.017	41	53
43848 K	BUENOS AIRES	979 716.75	0.018	39	56
43848 L	BUENOS AIRES	979 688.37	0.024	4	6
43848 M	BUENOS AIRES	979 689.35	0.022	6	6
43858 J	CANUELAS	979 735.29	0.021	8	8
43858 K	LA NORIA	979 747.51	0.025	16	0
43858 M	MONTE	979 782.39	0.028	8	0
43914 K	CORDOBA	979 312.34	0.026	14	40

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT
43914 L	CORDOBA	979 312.14	0.028	14	0
43920 K	ROSARIO	979 547.15	0.021	0	28
43934 K	RIO CUARTO	979 472.69	0.025	0	28
43982 K	BAHIA BLANCA	980 052.78	0.022	4	36
43982 L	BAHIA BLANCA	980 052.91	0.026	4	4
44030 A	SANTIAGO	979 414.11	0.030	15	16
44030 J	SANTIAGO	979 434.23	0.033	7	1
44030 K	SANTIAGO	979 434.68	0.030	9	12
44030 L	SANTIAGO	979 434.72	0.032	5	5
44031 K	VALPARAISO	979 620.87	0.044	1	2
44031 L	VALPARAISO	979 618.90	0.045	1	2
45164 B	AUCKLAND	979 934.11	0.051	5	0
45164 C	AUCKLAND	979 926.04	0.053	5	4
45164 J	AUCKLAND	979 940.39	0.050	4	4
45164 K	AUCKLAND	979 933.37	0.056	4	0
45196 A	HASTINGS	980 073.89	0.031	8	2
45196 J	HASTINGS	980 028.57	0.028	8	8
45312 J	KEMPSEY	979 412.38	0.025	10	18
45312 K	KEMPSEY	979 422.15	0.027	10	0
45331 A	SYDNEY	979 671.86	0.021	41	8
45331 J	SYDNEY	979 684.80	0.019	24	70
45331 L	SYDNEY	979 681.98	0.032	2	0
45331 M	SYDNEY	979 655.23	0.027	4	0
45331 N	SYDNEY	979 653.04	0.022	33	0
45331 O	SYDNEY	979 594.02	0.024	17	0
45331 P	SYDNEY	979 591.02	0.026	5	0
45331 Q	SYDNEY	979 684.72	0.023	10	6
45459 J	CANBERRA	979 606.39	0.020	34	42
45459 K	CANBERRA	979 547.27	0.021	30	0
45459 L	CANBERRA	979 602.03	0.021	36	0
45466 J	ALBURY	979 757.64	0.023	10	0
45466 K	ALBURY	979 751.70	0.020	10	18
45474 A	MELBOURNE	979 965.18	0.020	34	22
45474 B	MELBOURNE	979 965.19	0.021	22	4

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
45474 C	MELBOURNE	979 965.18	0.020	34	0
45474 D	MELBOURNE	979 965.16	0.021	19	0
45474 E	MELBOURNE	979 965.34	0.023	11	0
45474 F	MELBOURNE	979 972.42	0.022	24	0
45474 G	MELBOURNE	979 972.64	0.042	2	0
45474 H	MELBOURNE	979 974.50	0.026	5	0
45474 J	MELBOURNE	979 948.21	0.022	25	0
45474 K	MELBOURNE	979 948.24	0.023	14	0
45474 L	MELBOURNE	979 948.23	0.022	29	0
45474 M	MELBOURNE	979 947.35	0.019	43	42
45474 N	MELBOURNE	979 947.33	0.021	29	1
45474 P	MELBOURNE	979 933.88	0.022	36	0
45474 Q	MELBOURNE	979 880.82	0.024	20	0
45474 R	MELBOURNE	979 951.09	0.028	3	0
45474 S	MELBOURNE	979 895.38	0.035	2	0
45715 A	PERTH	979 380.86	0.023	54	0
45715 B	PERTH	979 378.78	0.026	16	0
45715 C	PERTH	979 380.08	0.025	20	0
45715 J	PERTH	979 386.56	0.021	16	16
45715 K	PERTH	979 386.32	0.023	16	0
45715 L	PERTH	979 394.52	0.026	17	0
45715 M	PERTH	979 448.55	0.028	9	0
45715 N	PERTH	979 402.67	0.029	8	0
45715 P	PERTH	979 386.28	0.024	20	15
45715 Q	PERTH	979 400.11	0.034	2	0
46603 J	BRITSTOWN	979 044.91	0.027	0	15
46622 A	BEAUFORT WEST	979 254.54	0.030	6	0
46622 J	BEAUFORT WEST	979 249.42	0.026	12	23
46622 K	BEAUFORT WEST	979 237.03	0.030	6	0
46630 A	LAINGSBURG	979 372.46	0.028	8	0
46630 J	LAINGSBURG	979 375.33	0.025	8	21
46738 A	CAPETOWN	979 632.71	0.018	72	46
46738 B	CAPETOWN	979 638.93	0.019	36	0
46738 J	CAPETOWN	979 631.45	0.018	46	17
46738 K	CAPETOWN	979 631.45	0.018	60	23
46738 L	CAPETOWN	979 634.84	0.025	6	0
46738 M	CAPETOWN	979 635.65	0.022	12	0
46738 N	CAPETOWN	979 634.01	0.023	9	0
46738 O	CAPETOWN	979 631.48	0.021	9	3
46738 P	CAPETOWN	979 631.62	0.031	2	0
47503 K	CARMEN DE PATAGONES	980 224.72	0.024	0	36

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	NAME	GRAVITY VALUE	STD ERROR	TIMES TIED INT	TIMES TIED EXT
47535 K	TRELEW	980 438.70	0.026	7	29
47535 L	TRELEW	980 438.37	0.028	7	7
47557 B	COMODORO RIVADAVIA	980 646.61	0.040	2	0
47557 C	COMODORO RIVADAVIA	980 666.65	0.045	2	0
47557 K	COMODORO RIVADAVIA	980 648.03	0.028	13	34
47557 L	COMODORO RIVADAVIA	980 648.01	0.029	15	5
47557 M	COMODORO RIVADAVIA	980 647.00	0.037	4	4
47575 K	PUERTO DESEADO	980 840.60	0.030	0	30
47597 K	SAN JULIAN	980 997.56	0.031	1	35
47597 L	SAN JULIAN	980 997.64	0.035	1	8
47612 B	PUERTO MONTT	980 273.78	0.041	4	0
47612 J	PUERTO MONTT	980 282.22	0.035	4	8
47612 K	PUERTO MONTT	980 288.74	0.041	4	0
48714 A	WELLINGTON	980 251.00	0.029	7	0
48714 B	WELLINGTON	980 250.99	0.027	17	0
48714 C	WELLINGTON	980 279.09	0.037	2	2
48714 D	WELLINGTON	980 279.17	0.029	9	0
48714 E	WELLINGTON	980 291.94	0.028	7	2
48714 K	WELLINGTON	980 292.01	0.024	14	34
48732 A	CHRISTCHURCH	980 494.29	0.026	20	10
48732 E	CHRISTCHURCH	980 481.58	0.026	29	12
48732 F	CHRISTCHURCH	980 481.56	0.028	13	0
48732 K	CHRISTCHURCH	980 481.59	0.025	29	35
48732 L	CHRISTCHURCH	980 481.47	0.027	11	1
48750 A	DUNEDIN	980 727.53	0.031	14	2
48750 C	DUNEDIN	980 721.75	0.030	17	0
48750 D	DUNEDIN	980 726.61	0.028	13	12
49027 K	HOBART	980 435.48	0.077	0	2
51108 K	PUERTO SANTA CRUZ	981 030.28	0.032	0	28
51119 K	RIO GALLEGOS	981 191.38	0.033	11	41
51119 L	RIO GALLEGOS	981 191.52	0.036	5	5
51119 M	RIO GALLEGOS	981 189.02	0.036	6	2
51137 K	RIO GRANDE	981 417.03	0.038	6	6
51137 L	RIO GRANDE	981 417.22	0.037	6	14
51148 A	USHUAIA	981 465.39	0.046	2	0

IGSN71 ABSOLUTE GRAVITY VALUES

IGB NUMBER	---------- NAME ----------	GRAVITY VALUE	STD ERROR	TIMES TIED INT	EXT
51148 B	USHUAIA	981 468.33	0.040	8	0
51148 K	USHUAIA	981 468.72	0.038	9	11
51148 L	USHUAIA	981 468.69	0.038	15	11
51230 A	PUNTA ARENAS	981 300.49	0.040	8	0
51230 J	PUNTA ARENAS	981 315.22	0.036	13	8
51230 K	PUNTA ARENAS	981 296.70	0.035	17	4
51230 L	PUNTA ARENAS	981 297.61	0.035	5	28
51230 N	PUNTA ARENAS	981 320.81	0.041	5	0
59520 J	HALLETT	982 689.86	0.050	0	8
59673 J	MARBLE POINT	982 937.11	0.046	0	8
59676 A	MCMURDO SOUND	982 976.83	0.045	9	2
59676 C	MCMURDO SOUND	982 969.84	0.043	24	27
59676 D	MCMURDO SOUND	982 973.45	0.045	8	0
59676 L	MCMURDO SOUND	982 973.18	0.046	9	0
59676 N	MCMURDO SOUND	982 976.62	0.046	8	0

APPENDIX I

DESCRIPTION OF MEASUREMENTS USED IN ADJUSTMENT OF THE IGSN 71

TABLE OF CONTENTS

1. – PENDULUM MEASUREMENTS

1.1. Introduction

Although pendulum gravity measurements have been carried out for two centuries they still constitute one of the most difficult measurements if high accuracy is sought.

It was clear that if the gravity scale standardization problem was to be solved using pendulum measurements, then only the most advanced measuring techniques should be used. At the IGC meeting in Paris in 1956 a special Sub-Group with the late B.C. Browne as chairman was formed to discuss pendulum measurements. This Sub-Group issued a memorandum (Browne, 1962a) which considered three aspects of these measurements :

(i) Theoretical considerations,

(ii) Design and construction of apparatus,

(iii) Observational problems.

Concurrently several observers attempted to increase the accuracy of the pendulum observations. The high precision measurements required for global gravity standards made it necessary to recheck all reduction formulas for systematic effects. A new correction term (Honkasalo, 1964a) was derived and applied to the tidal correction computed from Longman's formulas (Longman, 1959). A uniform method for reducing all pendulum observations was agreed upon at the Sub-Group meeting in Paris in 1965. it was also agreed that raw data for all measurements should be published so that a uniform procedure could be followed during adjustments.

It became clear that relatively few sets of pendulum apparatus were suitable for precise measurements; only the following instruments have been used in the IGSN 71 adjustments :

(I)	Gulf	(Woollard, Rose, 1963);
(II)	Cambridge	(Jackson, 1961);
(III)	IGC	(Mazzon, 1957. 1965);
(IV)	USCGS (NOS)	(Swick, 1942);
(V)	DO (EPB)	(Valliant, 1969a);
(VI)	GSI	(Muto, 1953).

Eighty-two percent of the actual measurements have been carried out with Gulf and Cambridge pendulum apparatus. There are some additional pendulum measurements that might have been used, but the number of measurements with each apparatus is not large enough to permit the determination of their proper weight relationship with the other measurements (e.g. Elstner, Schwarzberg, 1965).

o

o o

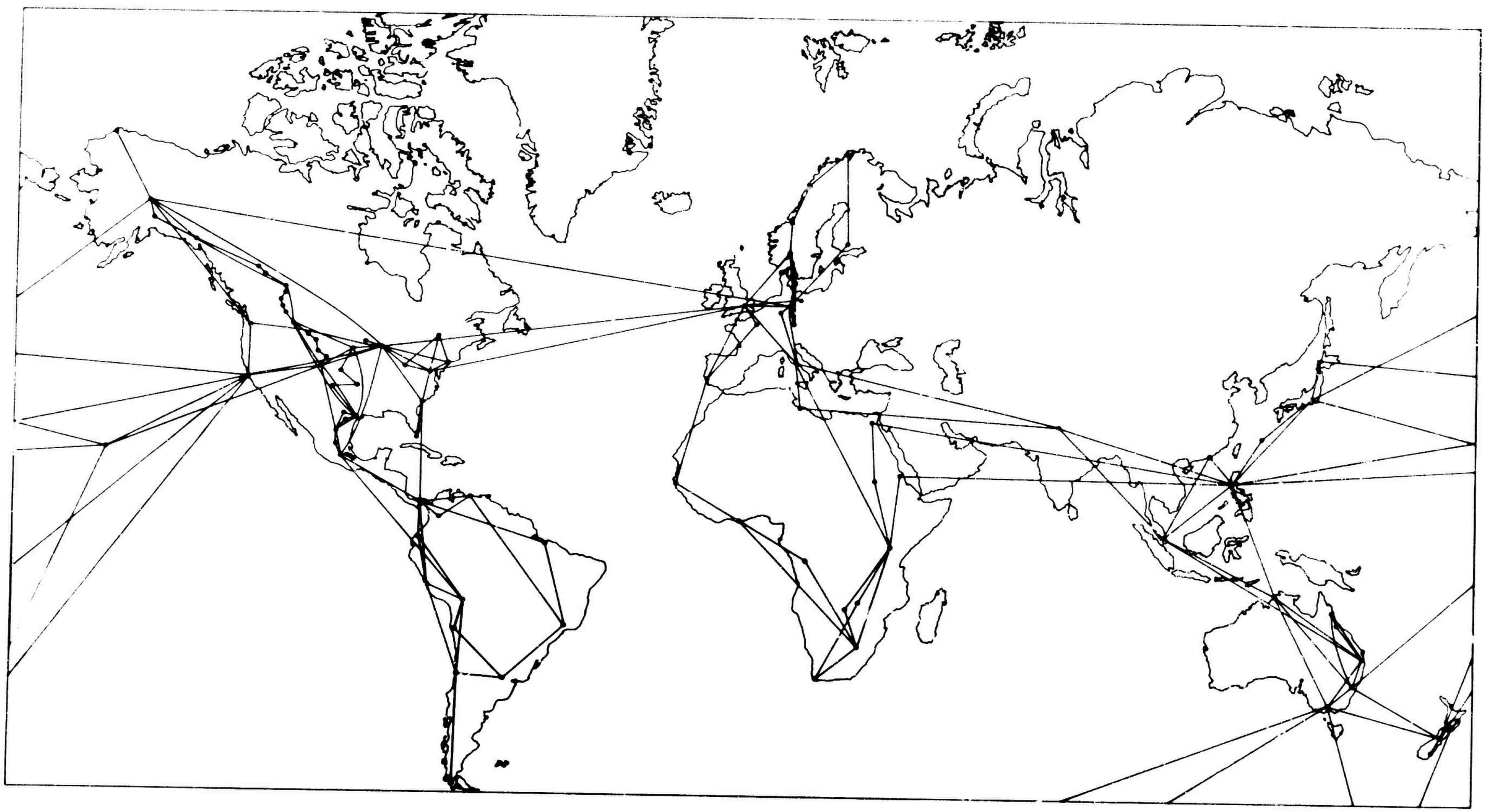


Fig. 1 : Gulf Pendulum Ties

1.2. Description of the Instruments and Trips

1.2.1. The Gulf Pendulum Apparatus *(Figure 1)*

This apparatus was developed in 1932 by the Gulf Research and Development Company as a geophysical prospecting instrument and consisted of two isochronous quartz minimum pendulums swinging simultaneously in antiphase in vacuum. The pendulums are transported in a clamped position within the apparatus. The pendulum knife-edges are made of ground and polished fused quartz and are swung on pyrex flats. In 1950 the instrument was adapted by Woollard, formerly of the University of Wisconsin, now the University of Hawaii, for scale standardization of North American gravity measurements. The first measurements with the C-set of pendulums gave poor results. Since 1953 sets M and K have been used. The instrument and the recording system have been improved several times during the measurements on the world network. The following trips are included in the IGSN 71 adjustment; the data have been extracted from (Woollard, Rose, 1963), (Woollard, 1965), (Woollard, Longfield, 1968) and private communications with Woollard.

Trip code	Year	Pend. sets	Observers	Number of Stations
GF01	53	K + M	J.C. Rose, E.A. Carlson	35 N. America
GF02	54-55	M	J.C. Rose, E.A. Carlson	21 N. America, Europe
GF03	55	M	J.C. Rose, K.H. Koenen	13 Africa
GF04	56-57	M	J.C. Rose, R.M. Iverson	16 Pacific
GF05	57	M	J.S. Watkins, R.M. Iverson	12 S. America
GF06	58	M	R.M. Iverson, T.S. Laudon	18 Far East, Pacific
GF07	58	M	R.M. Iverson, T.S. Laudon	10 S. America
GF08	59	K	R.M. Iverson, N.A. Ostenso	8 Africa
GF09	59	K + M	J.C. Rose, O. Strickholm	7 ECCL
GF10	60	M	J.C. Rose, O. Strickholm	8 Europe
GF11	60	K + M	O. Strickholm, W. Unger	2 Washington - Ottawa
GF12	60-61	M	O. Strickholm	5 Antarctica
GF13	61	M	J.C. Rose, O. Strickholm	3 Washington - Ottawa
GF14	61	M	R. Longfield, B. Carlson	3 Local
GF15	61	M	R. Longfield, B. Carlson	13 N. America
GF16	62	K + M	R. Longfield, B. Carlson	5 ECCL
GF17	63	M	R. Longfield, B. Carlson	13 Europe
GF18	64	M		10 America
GF19	65-66	M		15 World

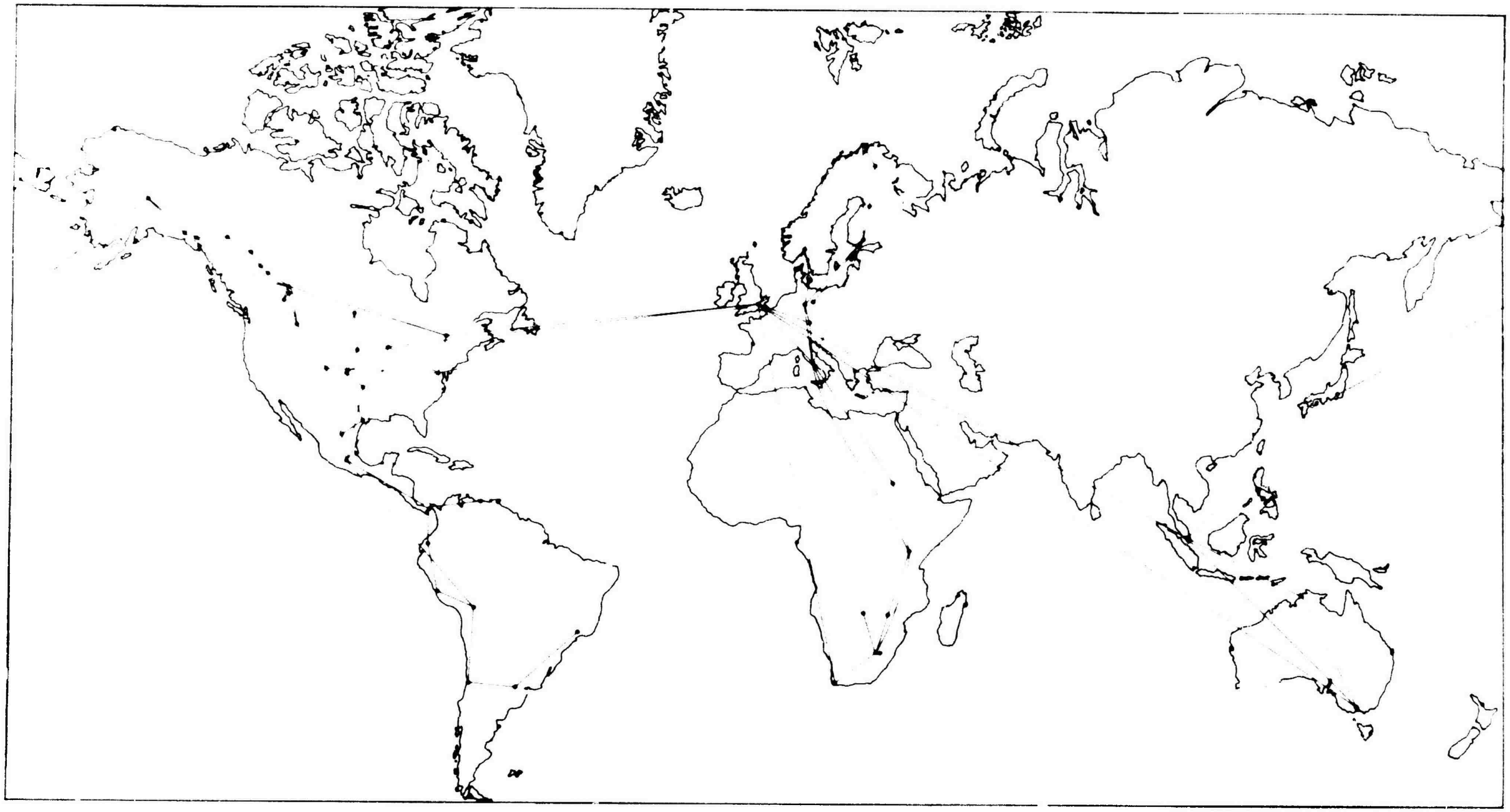


Fig. 2 : Cambridge Pendulum Ties

1.2.2. The Cambridge Pendulum Apparatus *(Figure 2)*

This apparatus was constructed in 1926 by Lennox-Conyngham. His three pendulum apparatus was rebuilt in 1930 as a two pendulum apparatus (Jackson, 1961). It consists of three isochronous invar pendulums of "Sterneck-type" with stellite knife-edges and agate flats. Two of these are swung simultaneously in antiphase to cancel the effect of sway of the instrument and pillar. The pendulums are transported separately by the observer as hand baggage. The three pendulums can be swung in three different pairs. Originally only two pairs were observed, but since 1963 observations have been made symmetrically in the order IA + IB, IB + IC, IC + IA. In 1931 another pendulum set, VI A, VI B, VI C, was constructed. These are not synchronous with set I. Thus a maximum of six pairs can be used although some trips have been made with only one pendulum set.

The comparison of the earlier Cambridge pendulum measurements with the Gulf pendulum observations showed a systematic scale difference of up to one part in 2500. This was found to be caused by the effect of the earth's magnetism on the Cambridge pendulums. Since 1952 the pendulums have been demagnetized before the observations at every station if a magnetic moment was detected; the vertical component of the earth's magnetism was cancelled with a Helmholtz-coil during the observations. The pendulums are swung in an East-West direction. The observations before 1952 have not been used for IGSN 71 computations.

The apparatus is not temperature controlled and a correction to standard temperature (+ 20° C) must be made. The redetermination of the temperature correction formula and its coefficients was made by T. Honkasalo in Helsinki for the pendulum pairs I CA and VI CA in 1963 (Honkasalo, 1968). The amendments to the corrections for other pendulum pairs was differentially derived from a great number of field measurements (Honkasalo, 1964b).

The following observations have been used :

Trip code	Year	Pend. sets	Observers	Number of Stations	References
CB01	52	I-AB I-AC VI-BC	G.D. Garland	10 N. America	(c), Garland, 1953
CB02	53	I-AB I-AC VI-BC	G.D. Garland	11 N. America	(c), Garland, 1955
CB03	54-55	I-AB I-AC VI-BC	G.D. Garland A.H. Cook	3 Europe America	(c), Garland, Cook, 1955
CB04	55	I-AB I-AC VI-AB VI-BC	G. Jelstrup	7 Europe	(c), Jelstrup, 1957
CB05	56	I-AB I-AC VI-AB VI-BC	D.I. Gough	4 Africa	(c), Gough, 1958
CB06	58	I-AB I-AC VI-AB VI-BC	B.C. Browne	8 Europe Africa	(c), Browne, 1962b
CB07	58	I-AB I-AC VI-AB VI-BC	J.E. Jackson	11 America	(c), Jackson, 1959
CB08	59	I-AB I-AC VI-AB VI-BC	J.E. Jackson	4 Australia	(c), Jackson, 1960
CB09	60	I-AB I-AC	T. Honkasalo	5 Europe	(c), Honkasalo, 1960
CB10	63	I-AB I-BC I-CA VI-AB VI-BC VI-CA	T. Honkasalo J.E. Jackson	8 Europe Africa	Honkasalo et al., 1967
CB11	64	I-AB I-BC I-CA VI-AB VI-BC VI-CA	D.I. Gough B.C. Browne	11 America	Honkasalo et al., 1967
CB12	67	I-AB I-BC I-CA VI-AB VI-BC VI-CA	B.C. Browne	5 Pacific	Browne, Honkasalo 1969.

The reference (c) is (Honkasalo, 1968).

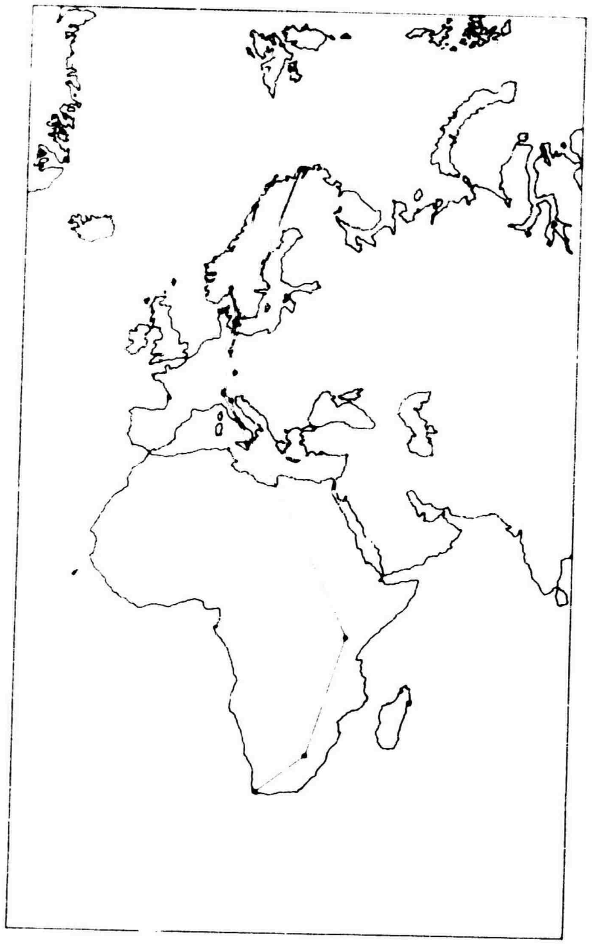


Fig. 3 : C G I Pendulum Ties

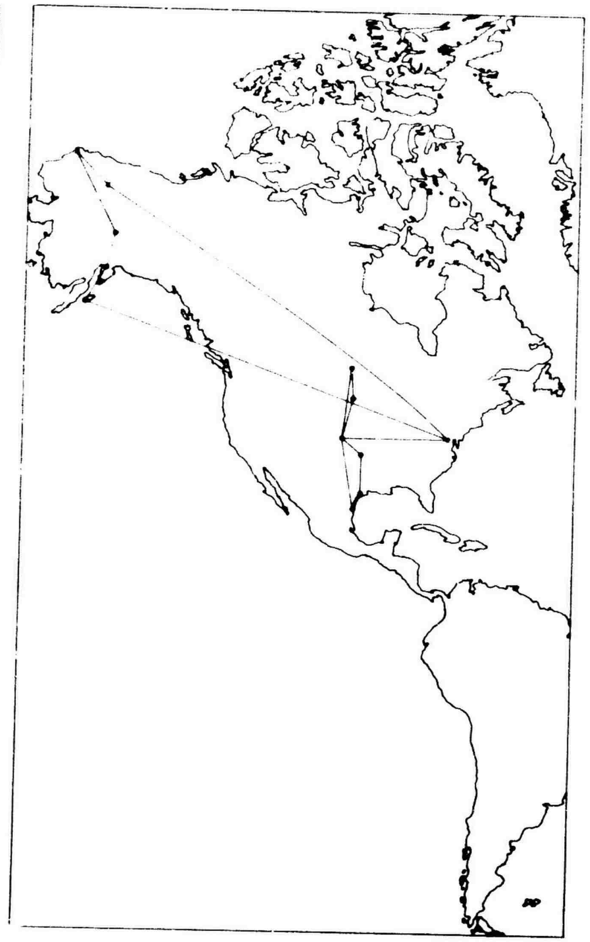


Fig. 4 : U S C G S (N O S) Pendulum Ties

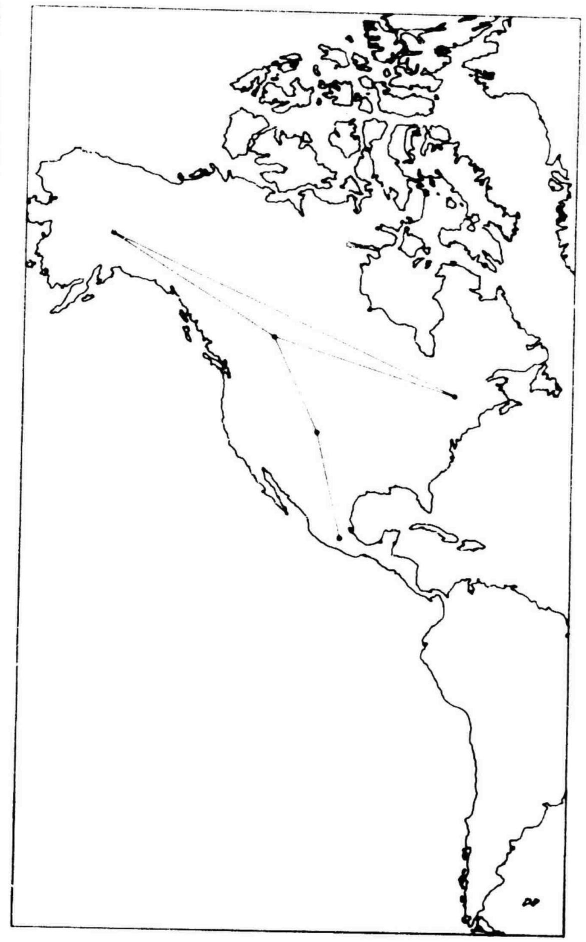


Fig. 5 : D O (E P B) Pendulum Ties

1.2.3. The Italian Geodetic Commission Pendulum Apparatus *(Figure 3)*

Constructed at the Istituto di Topografia, Geodesia e Fotogrammetria del Politecnico di Milano in 1948-54, it consists of three molybdenum minimum pendulums transported in clamped position in the apparatus. The pendulums are isochronous and two are swung with equal amplitudes in antiphase, the third pendulum at rest at the beginning (Vening-Meinesz type). Two fictitious pendulums are simultaneously observed photoelectrically (Mazzon, 1957 and 1965).

Three different instruments were used in the measurements of the world net. In the first instrument pendulums with steel knife-edges were swung on agate flats. In the other instruments the pendulums had agate knife-edges.

The pendulum apparatus was successfully transported by car but the handling during loading and unloading at the airports in Africa caused serious damage to the apparatus.

Data from the following trips are included in the IGSN 71 adjustment :

Trip code	Year	Pend. sets	Observers	Number of Stations	References
IT01	57-58	1	C. Mazzon, L. Pieri	6 Europe	Mazzon, Pieri, 1959
IT02	59	1	C. Mazzon	6 Europe	Mazzon, 1961a-b
IT03	63	3	C. Mazzon, V. Tomelleri	7 Europe	Mazzon, 1967
IT04	63	3	C. Mazzon, V. Tomelleri	4 Africa	Mazzon, 1967

1.2.4. The U.S. Coast and Geodetic Survey (National Ocean Survey) Pendulum Apparatus *(Figure 4)*

This apparatus was constructed by E.J. Brown in 1930. The swinging period of a single invar pendulum is observed photoelectrically. The sway of the support is observed interferometrically (Swick, 1942). The pendulum is transported in clamped position in the apparatus. The agate flat is fastened to the pendulum and the agate knife-edge to the support. Two units of the Brown equipment were employed in measurements at eleven key stations in the United States, Canada and Alaska during 1952 and 1953. At all stations the pendulums were swung simultaneously a few feet apart, with the planes of swing at right angles. Special efforts were made to minimize the systematic effects of temperature changes, variation in the vertical component of the earth's magnetic field from station to station and the sway of the pendulum support. The following trips are included in the IGSN 71 adjustment :

Trip code	Year	Pend. sets	Observers	Number of Stations	References
GS01	52	No. 2 and 3	N.E. Taylor	6 in Alaska	Rice, 1958
GS02	53	No. 2 and 3	G.R. Shelton	7 in USA and Canada	Rice, 1958

1.2.5. The Dominion Observatory (Earth Physics Branch) Pendulum Apparatus *(Figure 5)*

The apparatus was designed by L.G.D. Thompson in 1959 and rebuilt by H.D. Valliant (1969a). Bronze quarter-metre Mendenhall pendulums, constructed about the turn of the century by the U.S. Coast and Geodetic Survey, were used in this apparatus. Two isochronous pendulums with agate flats are swung on agate knife-edges with equal amplitudes in antiphase. The sway correction was computed with Andersen's formula. The apparatus is temperature controlled and the observations are computed to a nominal operating temperature of +40.0° C. As the pressure is maintained below 0.006 mmHg no correction is applied for changes in the air density. Two sets of three pendulums each are used. Twelve 900-second observations are made with each of the three possible pendulum pairs in each set.

Measurements made by Valliant on the American calibration line in 1967-68 (Valliant, 1969b), were included in the IGSN 71 adjustment. Actual pendulum periods were received through personal communication with Valliant.

1.2.6. The Geographical Survey Institute of Japan Pendulum Apparatus *(Figure 6)*

Constructed in 1951, it consists of three quartz minimum pendulums, of Vening Meinesz type, set in the same box. Two pendulums with steel knife-edges are swung on agate flats with equal amplitude in opposite phase and the third pendulum records the sway or movements of the apparatus. The periods of the pendulums were determined by comparing the signals from the oscillating pendulums directly with the time signal, both being recorded on the same chronograph tape (Muto, 1953).

In 1957 a new apparatus was constructed. The main pendulum case, timing system and temperature control box were rebuilt. The pendulums are swung in vacuum and are transported in a separate case (Inoue, 1961).

The following trips are included in the IGSN 71 adjustment :

Trip code	Year	Pend. sets	Observers	Number of Stations	References
JP01	55	1 - 3	T. Okuda, E. Inoue	2 Chiba Washington	Okuda et al., 1956
JP02	57-58	1 - 3	Y. Harada, H. Suzuki, S. Ohashi, S. Kakinuma	3 Singapore, Capetown	Harada et al., 1960
JP03	59	1 - 3 10 - 12	E. Inoue, T. Seto	2 Melbourne	Inoue, Seto, 1961
JP04	61-62	1 - 3 10 - 12	Y. Harada, S. Kakisuma J. Murata	3 Antarctic	Harada et al., 1963
JP06	65	1 - 3 10 - 12	H. Ishii, J. Murata	4 USA	Harada, 1967
JP07	65	1 - 3 10 - 12	H. Ishii, J. Murata	2 Fairbanks	Harada, 1967
JP08	66	1 - 3 10 - 12	H. Ishii, J. Murata	3 Manila, Singapore	Harada, 1967
JP09	67	1 - 3 10 - 12	H. Ishii, T. Seto	3 Sydney, Canberra	Harada, 1967

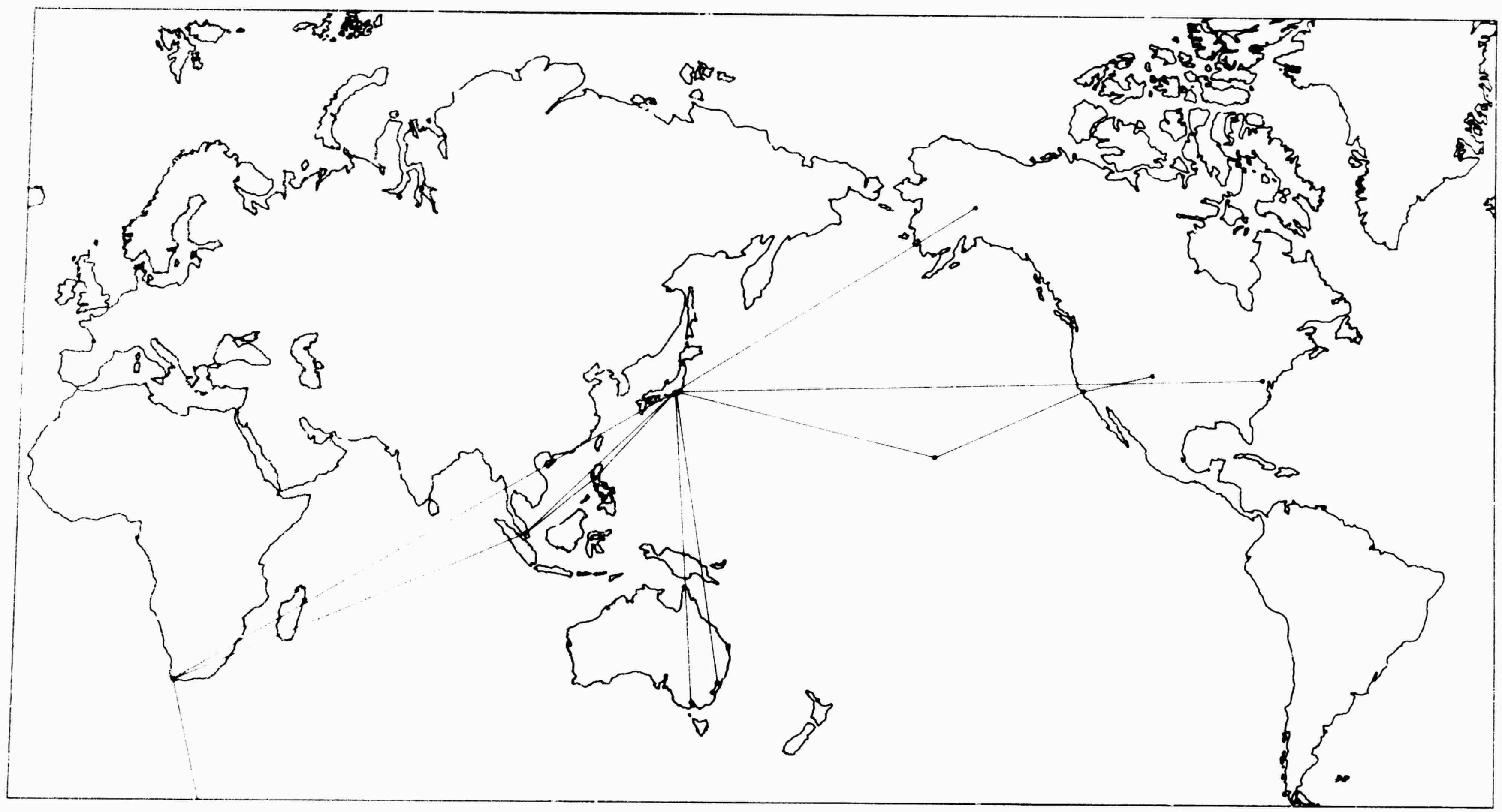


Fig. 6 : GSI Pendulum Ties

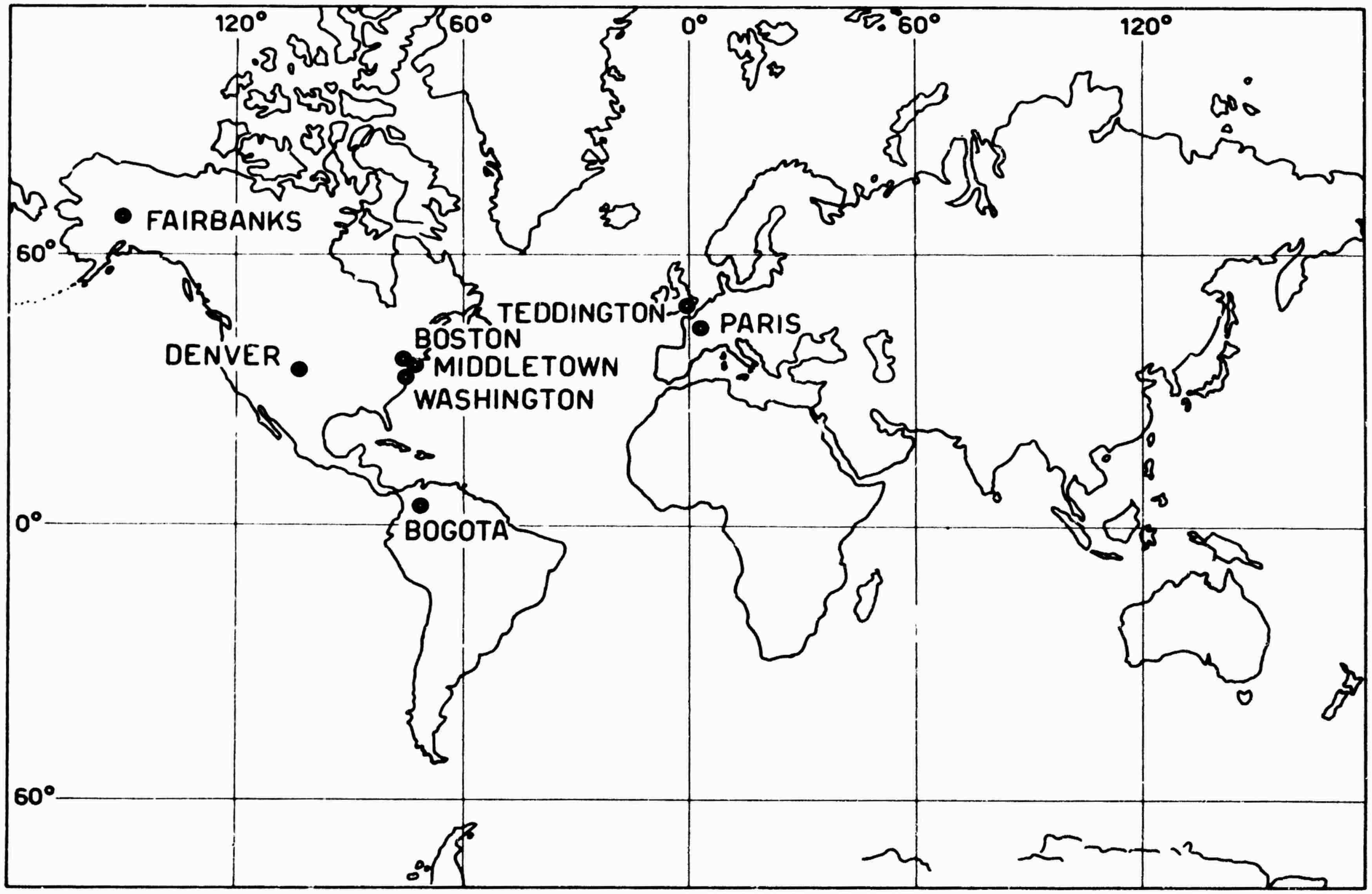


Fig. 7 : Location of Absolute Stations

2. – ABSOLUTE MEASUREMENTS

2.1. Introduction

Up to the present time relative gravity measurements were referred to a single absolute reference value determined by Kühnen and Furtwängler at Potsdam in 1906 by reversible pendulum experiments. This value (981 274. ± 3 mGal) compared with later measurements (reversible pendulum and free fall experiments) at various laboratories appeared to be too large by about 12 to 16 mGal.

The employment of modern technology for absolute measurements resulted in significant improvements during the 1960's. The utilization of new concepts (symmetrical experiments), white light and laser interferometers and modern nanosecond time counters increased measuring precision to the order of μ Gals and considerably reduced the systematic errors in the experiments. The transportable experiments (Hammond, Faller, 1971) permitted, for the first time, direct comparisons of various methods at the same site.

2.2. Recent Measurements

The new absolute measurements were made between 1965 and 1970 at the following locations (*Figure 7*):

Teddington,	U.K. (Cook, 1965a, 1965b, 1967; Cook, Hammond, 1969; Hammond, Faller, 1971);
Sevres,	France (Sakuma, 1966, 1969, 1971, Hammond, 1969; Hammond, Faller, 1971);
Gaithersburg,	Md., U.S.A. (Hammond, Faller, 1971);
Middletown,	Conn., U.S.A. (Hammond, Faller, 1971),
Bedford,	Mass., U.S.A. (Hammond, Faller, 1971);
Fairbanks,	Alaska, U.S.A. (Hammond, Faller, 1971);
Denver,	Col., U.S.A. (Hammond, Faller, 1971), and
Bogota,	Colombia (Hammond, Faller, 1971)

Other measurements made during the same period in Gaithersburg (Tate, 1968) and Princeton University (Faller, 1963, 1965a, 1965b) were not used due to their larger standard deviations (± 0.3 to ± 0.7 mGal).

The measurements considered for the IGSN 71 were :

(i) *Cook's experiment* at the National Physics Laboratory, Teddington made by timing of the symmetrical free motion of an upward projected glass ball. The ball was timed at its passage across two horizontal measurement planes on the way up and again on the way down. The distance between the two planes was measured interferometrically in terms of the international wave-length definition of the meter.

(ii) *Sakuma's experiment* at the Bureau International des Poids et Mesures (BIPM) Sèvres, France, a symmetrical free motion type experiment with projected back-to-back corner cube assembly detected by interferometric measurements. This permanent fixed location apparatus, developed and improved during the past decade, achieved a sensitivity of 3 μGal (3×10^{-9} g); systematic errors have also been significantly reduced during the last three years. This apparatus has achieved the highest precision to date in absolute gravity measurements.

(iii) The laser interferometer apparatus developed by *Faller and Hammond,* a transportable free fall apparatus. The falling body is one of the corner cubes of the interferometer; the other cube is held by a vertical seismometer mount at the top of the instrument to reduce the effect of seismic disturbances. A stabilized He-Ne laser light reflected from the falling corner cube generates high quality fringes which are detected and counted. Two fringe counters are started simultaneously shortly after the release of the cube; each is stopped after a different time interval. The acceleration of gravity is computed from the two precisely determined time intervals (± 2 nsec), the number of fringes counted and the wave-length of the laser. The standard deviation of each 50 drop data set (0.5 hours) is about 0.1 mGal. A large number of these sets are measured at each site and the gravity value is computed as the mean of the average value from each set. The standard deviation of this mean is normally about 0.03 mGal. After allowing for estimated errors in the corrections for systematic effects, the estimated error quoted for the final g value is about ± 0.04 mGal.

The complete list of the absolute observations considered with location, reference, method and measured g-value, is given below. IGB Code letters are given for the stations.

(1) *National Physics Laboratory, Teddington*

B.H. Rm B. 17 Teddington E	Cook, 1967	SFM photoelectric detection	981 181.82 ± 0.13
B. H. Rm B. 17 Teddington E	Cook, Hammond 1969	*Revised*	981 181.88 ± 0.13
B. H. Rm B. 17 Teddington E	Hammond, Faller, 1971	TPFF moving interferometer	981 181.930 ± 0.042

(2) *Bureau Int. des Poids et Mesures, Sèvres*

Paris A Room 1 BIPM Lab.	Sakuma 1967	SFM moving interferometer	980 925.975 ± 0.01
Paris A Room 1 BIPM Lab.	1969 * Sakuma	SFM moving interferometer	.965 ± 0.006
Paris A Room 1 BIPM Lab.	1970 * * Sakuma	SFM moving interferometer	.957 ± 0.005
Paris A Room 1 BIPM Lab.	Hammond, Faller, 1971	TPFF moving interferometer	980 925.960 ± 0.041

(3) *National Bureau of Standards, Gaithersburg, Md., U.S.A.*

NBS-2, Rm 129 Bldg. 202 Washington V	Tate 1968	TPFF, Photoelectric detection	980 101.8 ± 0.3
NBS-3, Rm 01 Bldg. 202 Washington 1	Hammond, Faller, 1971	TPFF moving interferometer	980 102.394 ± 0.055

* From Hammond, Faller, 1971

** Personal communication August 1970.

(4) *Air Force Cambridge Research Laboratories, Bedford, Mass., U.S.A.*

Pier no. 1 Gravity-Seismic Obs. Bldg. 1111 Boston A	Hammond, Faller, 1971	TPFF moving interferometer	980 378.671 ± 0.042

(5) *Scott Lab. of Physics, Wesleyan University, Middletown, Conn., U.S.A.*

Rm 18, Scott Lab. Middletown A	Hammond, Faller, 1971	TPFF moving interferometer	980 305.306 ± 0.041

(6) *Geophysical Inst., Univ. of Alaska, Fairbanks, Alaska, U.S.A.*

Rm. No. 1 Patty Bldg. Fairbanks E	Hammond, Faller, 1971	TPFF moving interferometer	982 234.953 ± 0.042

(7) *University of Denver, Denver, Colorado, U.S.A.*

Rm. 8 Science Hall Denver A	Hammond, Faller, 1971	TPFF moving interferometer	979 597.708 ± 0.042

(8) *Universidad Nationale de Colombia, Bogoto, Columbia.*

Quarto 111 Edificio Matematicia y Fisica Bogota C	Hammond, Faller, 1971	TPFF moving interferometer	977 390.015 ± 0.087

The values given above are reduced to the floor at each of the sites. The results are also corrected for the local earth tide. The Honkasalo correction (Honkasalo, 1964a) is included only in Sakuma's values. The standard deviation quoted for Sakuma's values represents the internal consistency of each set of measurements.

2.3. Absolute g Values for the Adjustment of the IGSN 71

After taking into account the Honkasalo and local tie corrections the following absolute gravity values were introduced into the final adjustment :

Site	Author	Honkasalo correction	Final Value
841C Bogota	Hammond, Faller, 1971	- 0.036	977 389.979 ± 0.087
11994A Denver	Hammond, Faller, 1971	+ 0.008	979 597.716 ± 0.042
11687V Washington	Hammond Faller, 1971	+ 0.007	980 101.271 ± 0.055
15212A Middletown	Hammond, Faller, 1971	+ 0.012	980 305.318 ± 0.041
15221A Boston	Hammond, Faller, 1971	+ 0.014	980 378.685 ± 0.042
18082A Paris	Hammond, Faller, 1971	+ 0.026	980 925.986 ± 0.041
18082A Paris	Sakuma (1970)	(included)	980 925.957 ± 0.030
18110A Teddington	Cook (1969)	+ 0.031	981 181.84 ± 0.13
18110A Teddington	Hammond, Faller, 1971	+ 0.031	981 181.891 ± 0.050
23147F Fairbanks	Hammond, Faller, 1971	+ 0.054	982 235.007 ± 0.042

o

o o

3. – GRAVIMETER MEASUREMENTS

3.1. Introduction

The gravimeter measurements used in the adjustment of the IGSN 71 had to meet two basic requirements :

(a) a degree of relative accuracy compatible with the accuracy sought for the Net; and

(b) a sufficient number of measurements with each instrument to be suitable for statistical analysis.

The following gravimeters have been considered capable of meeting the relative accuracy required for the data : Askania, LaCoste and Romberg, North American, Western and Worden. Only small dial observed Δg's with Worden gravimeters have been considered since large dial measurements contain unacceptably large errors.

Two main groups of gravimeter data have been organized :

(i) LCR measurements, for which observation dates and actual readings are available at each station. Generally these have been observed in ladder sequence (ABCD ... DCBA) but some are single ties only (ABCD ... XYZA);

(ii) non LCR measurements, for which only the computed gravity differences are available. These were generally obtained from repeated forth-and-back measurements between consecutive stations and had been corrected for drift and earth tides.

3.2. Description of the Trips considered for the IGSN 71

3.2.1. Trip Coding

The gravimeter trip code consists of 4 digits; the first two digits identify the sponsoring agency, the next two digits represent sequential trip numbers. Non LaCoste and Romberg gravimeter trip codes start at 50. LCR trip codes start at 01.

The code for the gravimeters also consists of four characters. They are : a letter (A = Askania, E = Western, L = LaCoste and Romberg, N = North American, W = Worden) followed by the original serial number of the instrument. For the large model LCR meters, 800 has been added to the actual serial number (e.g. L801 = large model LCR no. 1).

Fig. 8 : Gravimeter ties made by HIG

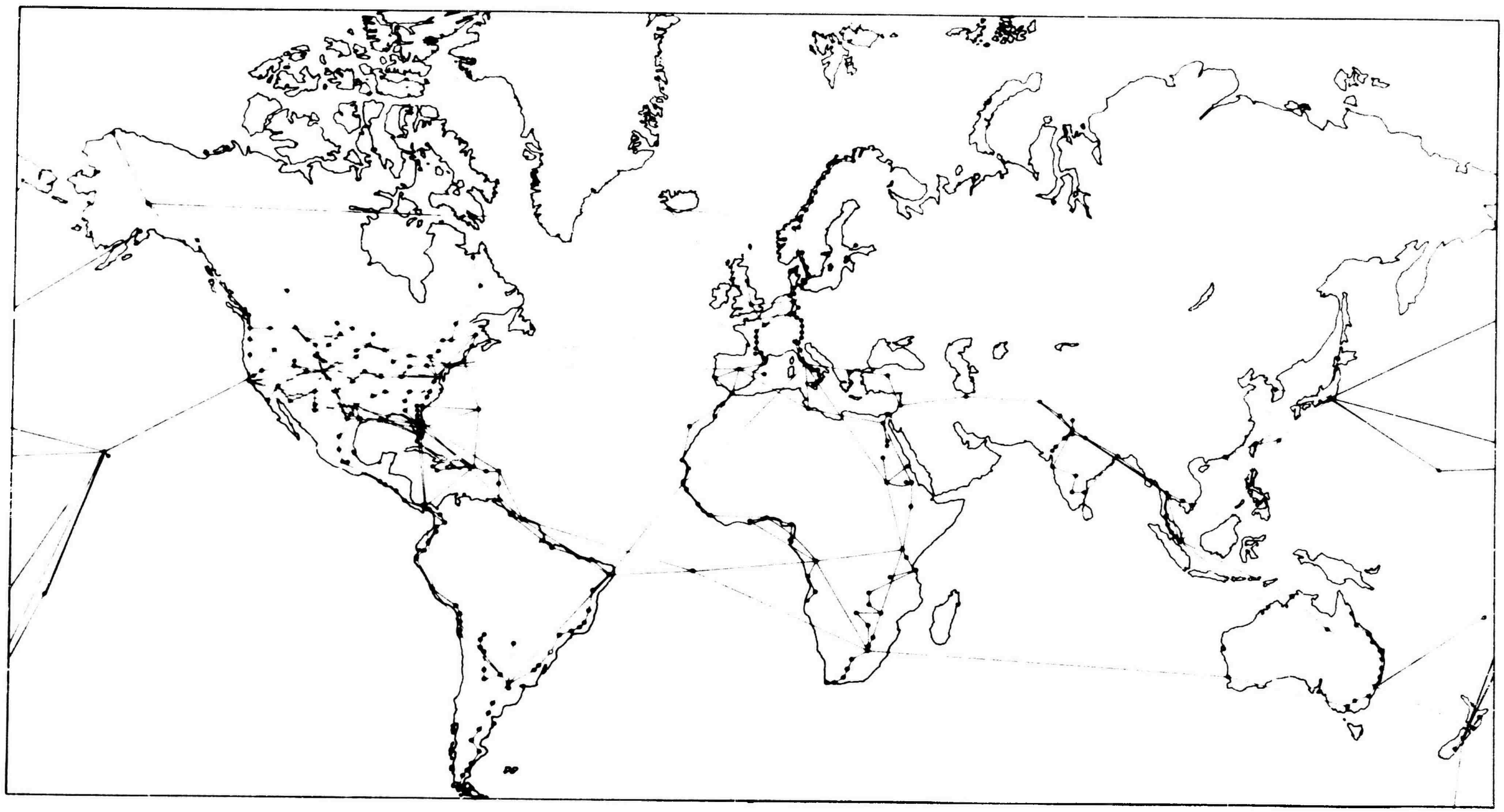


Fig. 9 : Gravimeter ties made by 1GSSq

3.2.2. Trips performed by Woollard's Group (UW and HIG ; *Figure 8*).

Agency Code 01.

Trip code	Year	Day	GVMTRS	Area
0101	61	296 - 364	L801	ACL Paso de Cortes North
0102	62	63 - 65	L801	tie Madison - Denver
0103	63	166 - 285	L801 , L807	EACL
0104	64	219 - 284	L801 , L807	ACL La Paz North
0105	65	71 - 83	L801 , L093	ACL Mexico - Austin
0106	65	126 - 135	L807	tie Madison - Washington
0107	65	140 - 298	L807 , L090	ACL La Paz North
0108	65	160 - 185	L801 , L093	ACL Paso de Cortes North
0109	65/66	189/32	L801 , L093	WPCL and World ties
0110	66	69 - 97	L801	tie Madison - Fairbanks - Mexico
0401	61	164 - 179	L001	ASCL Bogota - Caribou
0402	61	196 - 332	L001	WPCL
0801	64	58 - 85	L801 , L807	ACL Panama North
0414	66	81 - 157	L093	NGBN Phase I
0417	67	73 - 92	L115 , L137	ACL Mexico North

The observations have been communicated by Prof. G.P. Woollard of the H.I.G., Honolulu, Trip 0102 has been rejected because of inconsistencies in the data.

3.2.3. Trips performed by the 1st Geodetic Survey Squadron, Cheyenne (formerly 1381GSSq, Orlando ; *Figure 9*).

Agency Code 04.

Trip code	Year	Day	GVMTRS	Area
0401	61	164 - 179	L002	ASCL Bogota - Caribou
0402	61	196 - 332	L002, L012	WPCL
0403	63	160 - 172	L043, L044, L047, L048	ASCL Orlando - Caribou
0404	63	207 - 226	L043, L044, L047, L048	ACL Houston North
0405	63	317 - 347	L043, L044, L047, L048	ACL Houston South
0406	64	107 - 205	L043, L044, L047, L048	EACL Africa
0407	64	216 - 305	L043, L044, L047, L048	EACL Europe
0408	64/65	320 / 116	L043, L044, L047, L048	WPCL and CASCL
0409	65	146 - 161	L808, L048, L057	ASCL Orlando - Caribou
0410	65	164 - 206	L808, L048, L056	ASCL Orlando - Buenos Aires
0411	65	215 - 234	L808, L048, L056, L057	ASCL Orlando - Alert
0412	65	151 - 234	L043, L044, L047, L050	EASCL, Europe
0413	65	277 - 346	L043, L044, L047, L048	EASCL, Africa
0414	66	81 - 157	L043, L047, L048	NGBN Phase I
0415	66	162 - 265	L043, L044, L047, L048	World ties
0416	66 / 67	298 / 40	L043, L047, L093, L115	NGBN Phase II
0417	67	73 - 92	L803, L808, L002, L043, L044, L047, L048	ACL Mexico North
0418	67	289 - 311	L043, L044, L047, L048	Antarctic ties

The above trips were generally performed in ladder sequence and constitute the most relevant contribution to the gravimetric measurements for the IGSN 71. The data have been obtained from Mr. C.T. Whalen (Buteau and Whalen 1965; Whalen 1965a, 1965b, 1966b, 1966c; Whalen and Harris 1966; Whalen 1967a, 1967b; and private communications).

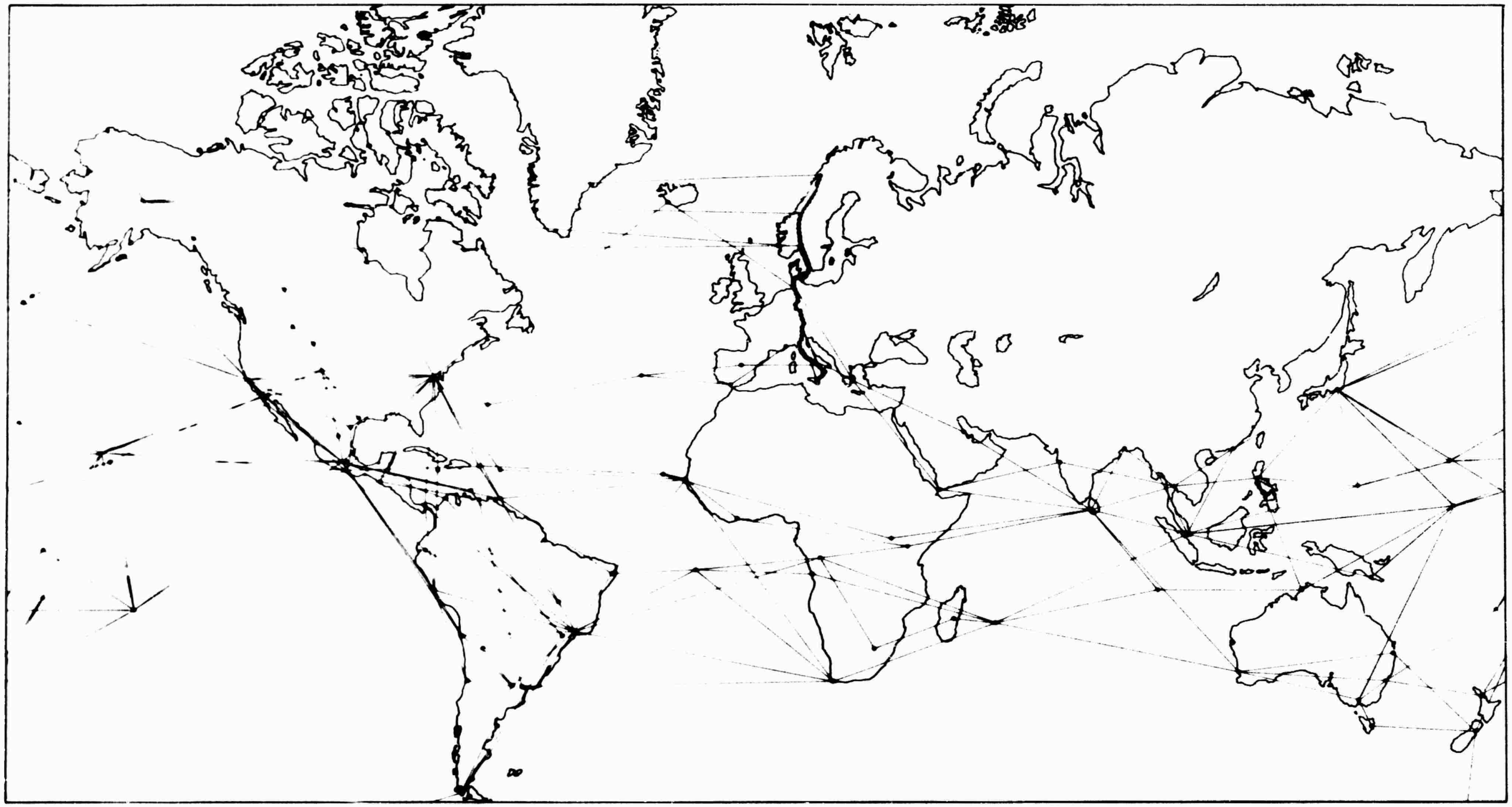


Fig. 10 : Gravimeter ties made by NAVOCEANO

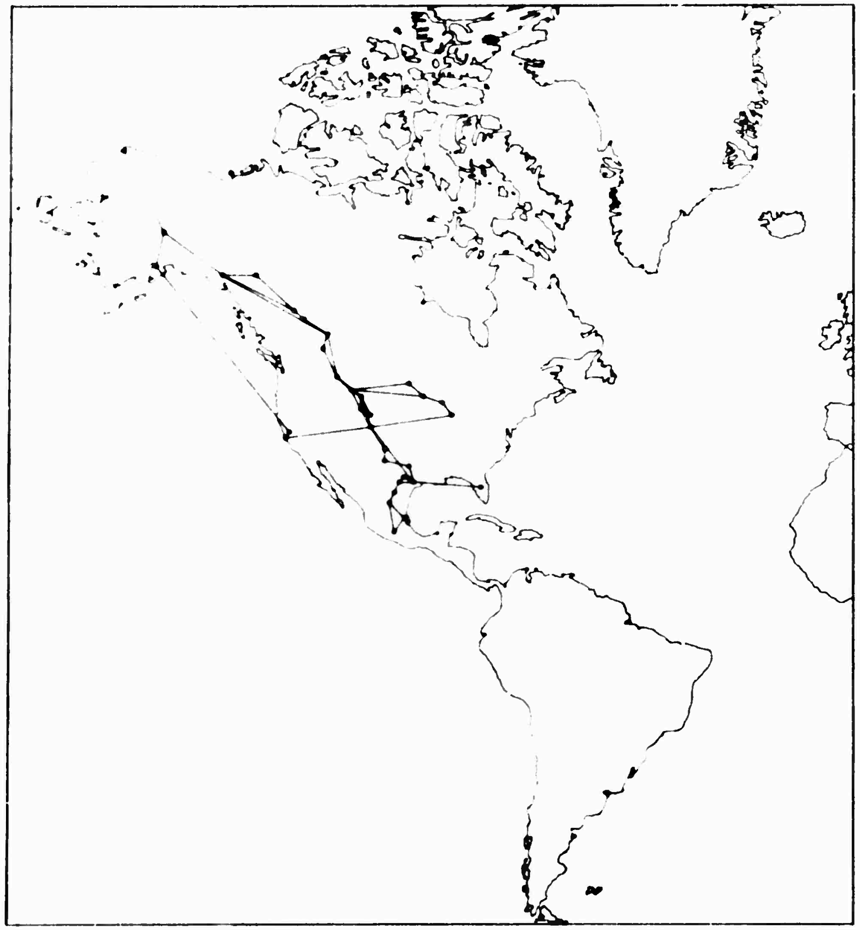


Fig. 11 : Gravimeter ties made by
TOPOCOM

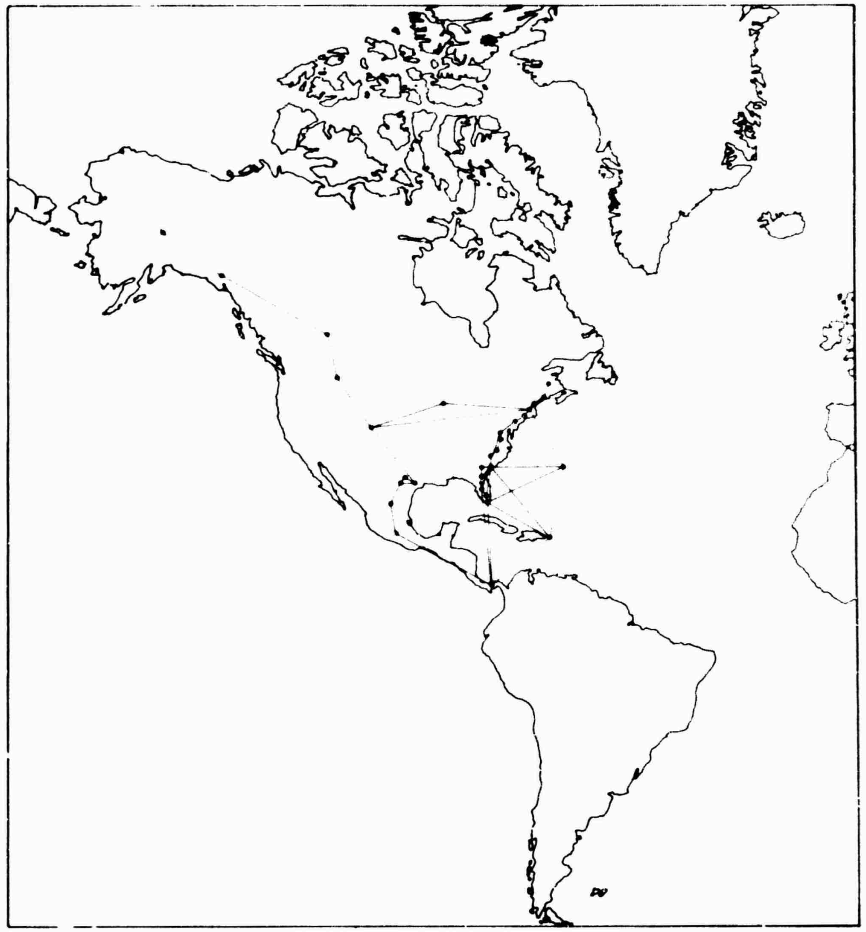


Fig. 12 : Gravimeter ties made by
AFCRL

3.2.4. Trips performed by NAVOCEANO, Washington (formerly USNOO ; *Figure 10*).

Agency Code 05.

Trip code	Year	Day	GVMTRS	Area
0501	62	285 - 337	L005	World ties
0502	63	137 - 197	L005 , L015	Detail ECL
0503	63	259 - 288	L005	N. America and Europe
0504	63	309 - 346	L005	World ties
0505	64	7 - 48	L005	South America
0506	64	77 - 121	L015	Central America, Africa, Australia
0507	64	191 - 224	L015	World ties
0508	64	265 - 278	L005, L015, L033, L050, L057, L061, L062, L072, L076, L081	ACL
0509	64	239 - 342	L005	World ties
0510	65	12 - 56	L015	South America, Africa
0511	65	187 - 233	L015 , L033	World ties
0512	65	285 - 325	L015 , L033	World ties
0513	66	10 - 55	L005, L015, L033	America, Africa
0514	66	88 - 129	L015 , L033	World ties
0515	66	101 - 153	L076 , L092	World ties
0516	66	136 - 176	L015 , L033	World ties
0517	66	191 - 234	L015 , L033	Europe, Asia
0518	67	10 - 58	L005 , L091	World ties
0519	67	40 - 78	L076	Europe, Asia
0520	67	106 - 122	L095 , L072	N. America, Europe

The data have been forwarded by Mr. A. L. McCahan, NAVOCEANO, in private communications between 1963 and 1967.

With the exception of trips 0502 and 0508, the measurements were made in one direction only.

3.2.5. Trips performed by TOPOCOM (formerly Army Map Service, Washington ; *Figure 11*).

Agency Code 06.

Trip code	Year	Day	GVMTRS	Area
0601	63	253 - 258	L045 , L046	ACL Houston - Paso de Cortes
0602	64	160 - 185	L019, L024, L055, L069	ACL
0404	63	207 - 226	L045 , L046	ACL Houston North
0417	67	73 - 92	L122 , L140	ACL Mexico North

The data have been received through Mr. C.T. Whalen, 1GSSq, Cheyenne.

3.2.6 Trips performed by the Terrestrial Sciences Laboratory, AFCRL, Bedford *(Figure 12)*.

Agency Code 08.

Trip code	Year	Day	GVMTRS	Area
0801	64	58 - 85	L803 , L808	ACL Panama North
0802	64	314 - 328	L803 , L808	ASCL Boston - Panama
0803	66	193 - 211	L803, L808, L002, L093	ACL Paso de Cortes North
0804	67	213 - 229	L808 , L002	ASCL Boston - Washington
0401	61	164 - 179	L803	ASCL Bogota - Caribou

The data have been received from Mr. B. Szabo, AFCRL, Bedford.

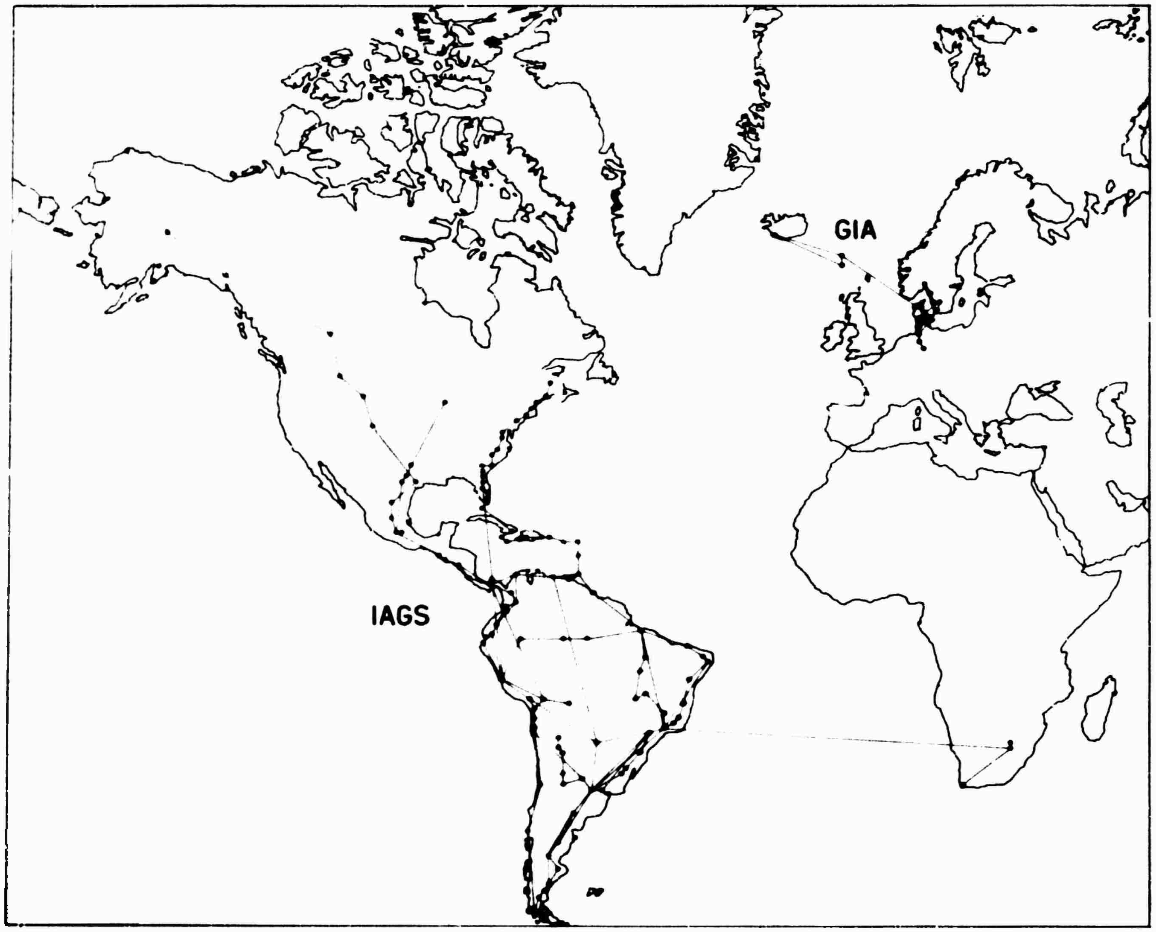


Fig. 13 : Gravimeter ties made by I A G S and G I A

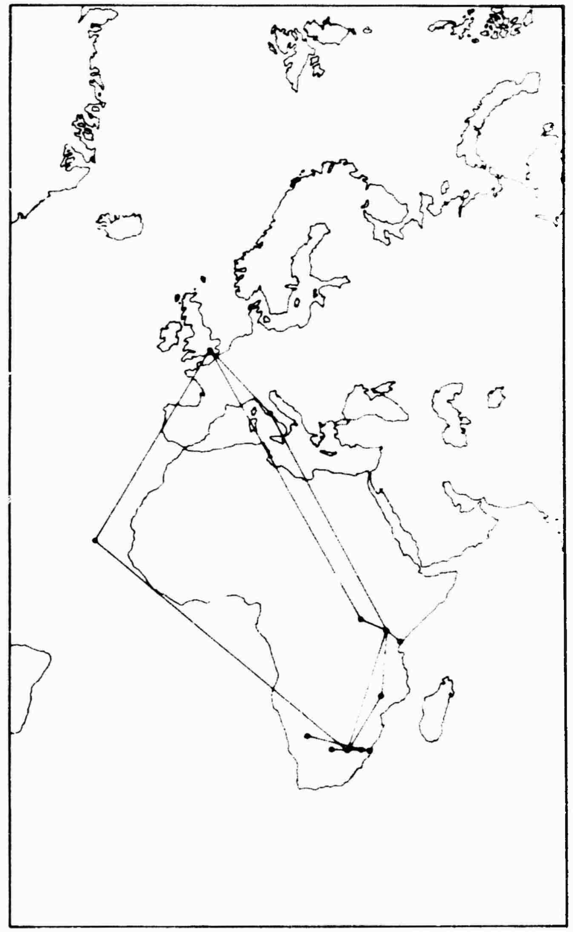


Fig. 14 : Gravimeter ties made by I G S

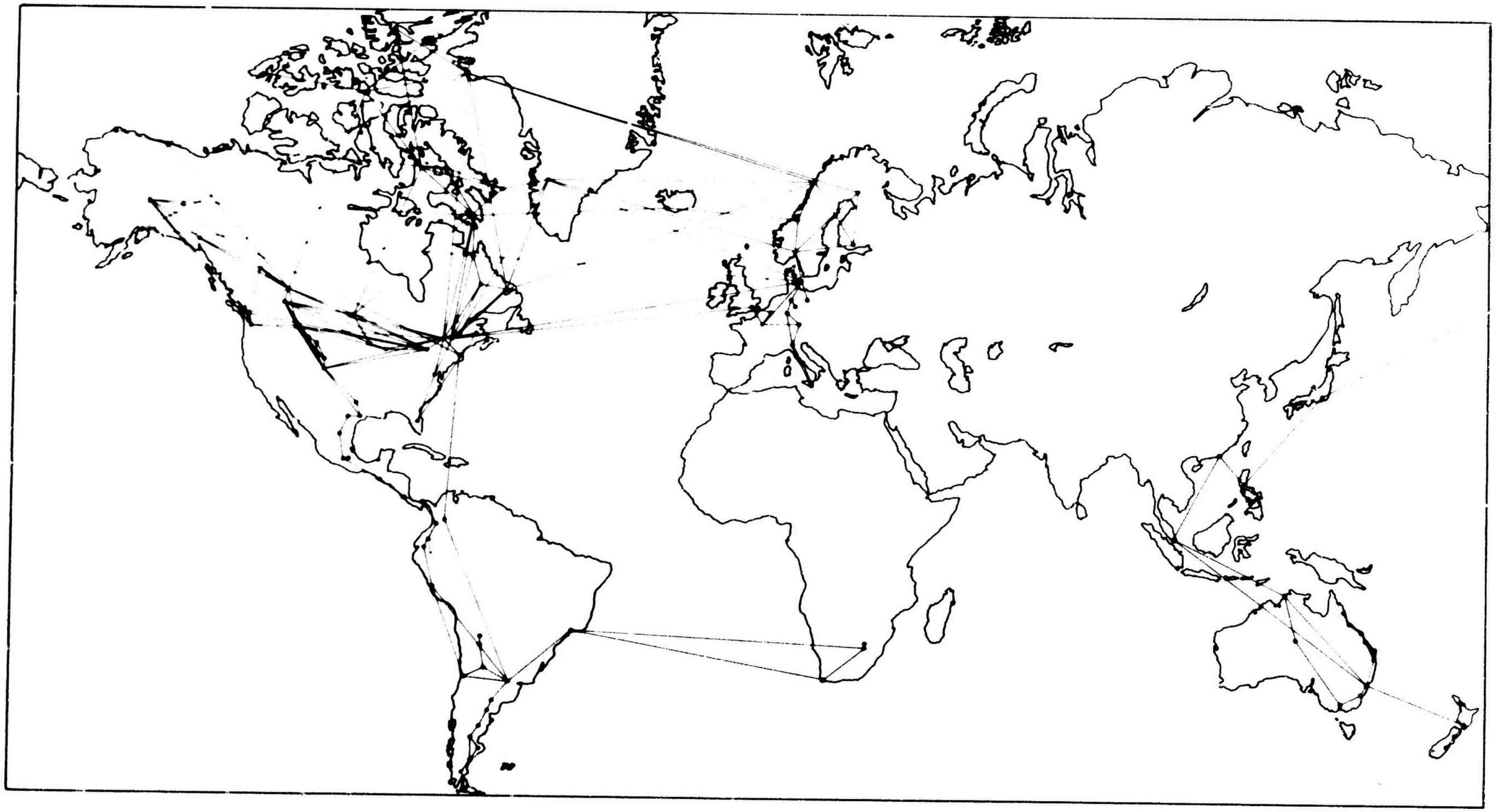


Fig. 15 : Gravimeter ties made by EPB

3.2.7. Trips performed by the Inter-American Geodetic Survey *(Figure 13).* Agency Code 09.

Trip code	Year	Day	GVMTRS	Area
0901	61	4 - 149	L004 , L011	ACL, ASCL, Madison South
0902	65 / 66	342 / 21	L056 , L057	Panama, Lima, La Paz
0404	63	207 - 226	L011	ACL Houston North
0405	63	317 - 347	L011, L056, L057	ACL Houston South
0409	65	146 - 161	L056	ASCL Orlando - Caribou
0410	65	164 - 206	L057	ASCL Orlando - Buenos Aires
1001	69	281 - 304	L056 , L057	Buenos Aires - Capetown

The data have been received through Mr. C.T. Whalen, 1GSSq, Cheyenne, except data for trip 1001 which has been forwarded by Prof. E. Baglietto, University of Buenos Aires.

3.2.8. Trip performed by the University of Buenos Aires. Agency Code 10.

Trip code	Year	Day	GVMTRS	Area
1001	69	281 - 304	L190 , L194	Buenos Aires - Rio de Janeiro - Johannesburg - Capetown

The data have been received from Prof. E. Baglietto, University of Buenos Aires.

3.2.9. Trips performed by Earth Physics Branch , Ottawa (formerly Dominion Observatory ; ***Figure 15*****).**
Agency Code 20.

Trip code	Year	Day	GVMTRS	Area
2001	61	116 - 189	L007	ASCL Ottawa North
2002	61	196 - 216	L007	Ottawa - Teddington
2003	61	339 - 342	L009	Ottawa - Montreal
2004	62	90 - 186	L009	ASCL Ottawa North
2005	62	256 - 265	L007 , L009	ASCL Ottawa North
2006	62	299 - 318	L007 , L009	ACL - ASCL Madison North
2007	63	26 - 32	L007 , L009	ASCL Ottawa North
2008	63	39 - 67	L007 , L009	EACL Europe
2009	63	84 - 133	L007 , L009	ACL
2010	63	337 - 348	L007 , L009	ASCL Ottawa North
2011	64	46 - 61	L007 , L009	ASCL Ottawa North
2012	64	75 - 106	L007 , L009	ASCL Ottawa North
2013	64	147 - 161	L007 , L009	tie ACL - EACL North
2014	64	194 - 215	L007 , L009	Ottawa - Winnipeg
2015	65	103 - 139	L009	ASCL Ottawa North
2016	65	243 - 319	L007 , L009	ACL Denver N. - EACL Europe
2017	65	338 - 350	L007 , L009	ASCL Ottawa North
2018	66	12 - 33	L007 , L009	ASCL Ottawa North
2019	66	228 - 295	L007 , L009	WPCL
2020	66	267 - 285	L074 , L075	ASCL Washington N.
2021	68	4 - 32	L007, L009, L074, L075	ASCL Ottawa North
2022	69	254 - 263	L009, L172, L173	ACL Denver - Point Barrow Fairbanks - Boston
0411	65	275 - 234	L007, L009, L074	ASCL Orlando - Alert
0415	66	162 - 265	L074 , L075	World ties
0417	67	62 - 97	L007 , L009	ACL Mexico North
1001	69	281 - 304	L009, L172, L173	Ottawa - Boston - Bogota Buenos Aires - Capetown

The data have been received in various communications from Dr. M. J. S. Innes, and Dr. J. G. Tanner of EPB, Ottawa.

3.2.10. Trips performed by the Institute of Geological Sciences, London (formerly Overseas Geological Survey ; *Figure 14*).

Agency Code 33.

Trip code	Year	Day	GVMTRS	Area
3301	65	175 - 287	L097	from Teddington to Africa
3302	66 / 67	261 / 32	L097	from Teddington to Africa

The data have been communicated by Dr. D. Masson-Smith and R. B. Evans of IGS, London.

3.2.11. Trips performed by the Geological Institute, Aarhus, Denmark (*Figure 13*).

Agency Code 42.

Trip code	Year	Day	GVMTRS	Area
4201	65	167 - 182	L054, L079, L085	tie EACL North to Iceland
4202	67	67 - 70	L054	ECL Hanover - Copenhagen
4203	67	195 - 214	L054	ECL Hanover - Oslo
4251	61		W142	ECL detail Krusaa - Helsingor
4252	61		W142	" " " "
4253	62		W142	" " " "
4254	65		W142	" " Copenhagen - Oslo

The data have been forwarded by Prof. S. Saxov of the Geological Institut, Aarhus.

3.2.12. Trips performed by the Deutsche Geodätisches Forschungsinstitut, Munich (*Figure 16*).

Agency Code 44.

Trip code	Year	Day	GVMTRS	Area
4401	65	252 - 279	L085 , L087	ECL Munich - Copenhagen
4402	66	290 - 295	L079, L085, L087	tie Bad Harzburg - Potsdam
4451	55		N140	ECL detail (Brein unp.)
4452	56		N140	ECL detail (Brein unp.)
4453	59		N140	ECL detail (Brein unp.)
4454	59		A085, A130	ECL detail (Böck, Bettac unp.)

The data have been communicated by Prof. M. Kneissl, DGFI , Munich.

3.2.13. Trips performed by the Geodätisches Institut, Hanover (*Figure 17*).

Agency Code 45.

Trip code	Year	Day	GVMTRS	Area
4501	67	142 - 168	L054, L079, L085	ECL Hanover - Hammerfest
4551			A130	ECL detail
4552			A130	" "
4553			A130	EACS
4554			A085, A130	"

The data observed with LCR gravimeters have been communicated by Prof. A. Schleusener; the non-LCR gravimeter data have been extracted from a paper by Prof. W. Torge (1966), and include the observations by Prof. Grossmann and Mr. Bettac.

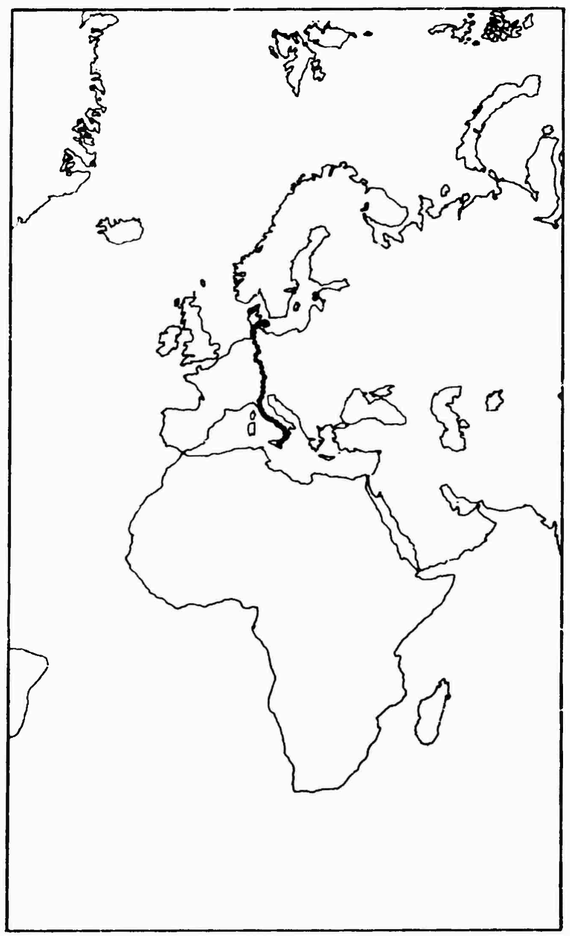


Fig. 16 : Gravimeter ties made by DGFI

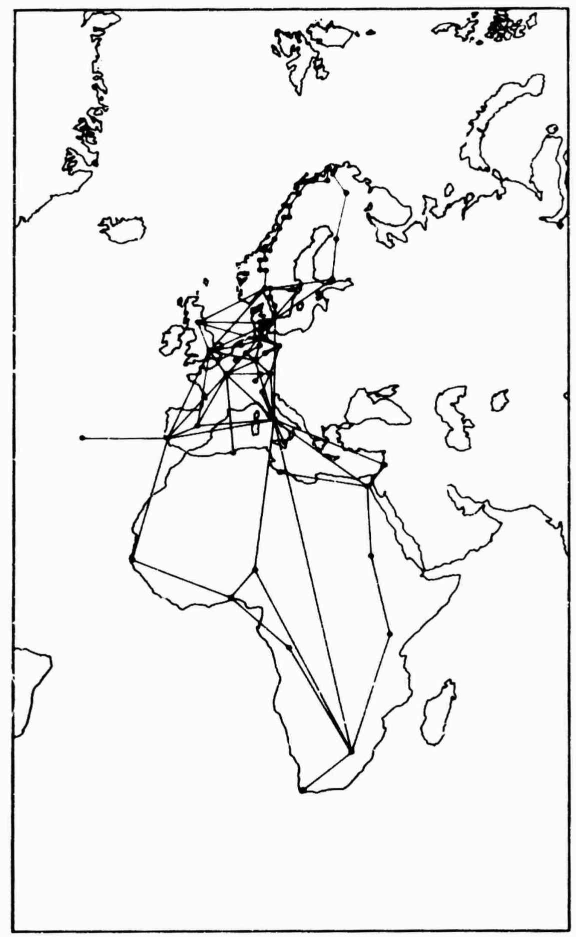


Fig. 17 : Gravimeter ties made by GIH

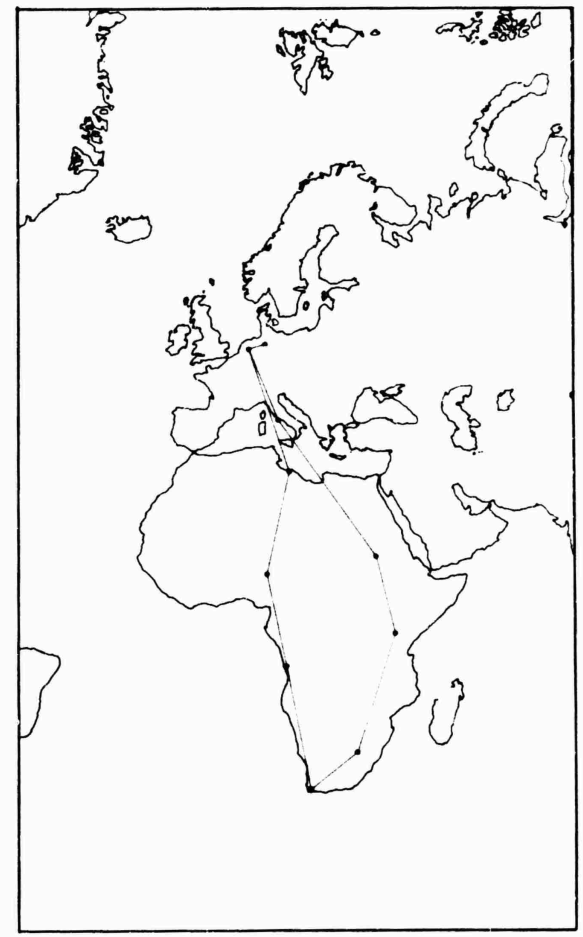


Fig. 18 : Gravimeter ties made by ITGH

3.2.14. Trip performed by the Technische Hochschule, Aachen.

Agency Code 48.

Trip code	Year		GVMTR	Area
4851	56		A085	ECL detail (Riemann, unp.) Flensburg to Bamberg

The data have been communicated by Prof. M. Kneissl, DGFI, Munich.

3.2.15. Trips performed by the Institut für Theoretische Geodäsie, Technische Hochschule, Hanover *(Figure 18)*.

Agency Code 49.

Trip code	Year	Day	GVMTRS	Area
4901	64 / 65	358 / 60	L079	EACS
4902	65	44 - 60	L085	EACS

The data have been communicated by Prof. W. Höpcke T.H., Hanover.

3.2.16. Trips performed by the Expedition Polaire Française and the ORSTOM *(Figure 19)*.

Agency Code 55.

Trip code	Year		GVMTRS	Area
5551	49 / 51		E042 , E047	Europe
5552	51		N124	EACS
5553	52		N124	EACS

The data have been reported by Dr. S. Coron (1968), from the previous papers by Martin (1955), Martin et al. (1954), Duclaux et al. (1952, 1954).

3,2,17. Trip performed by the Bundesamt für Eich-und Vermessungswesen, Wien.

Agency Code 58.

Trip code	Year		GVMTR	Area
5851	61		W500	ECL detail (Senftl, unp.) Bamberg to Brenner

The data have been communicated by Prof. M. Kneissl, DGFI, Munich.

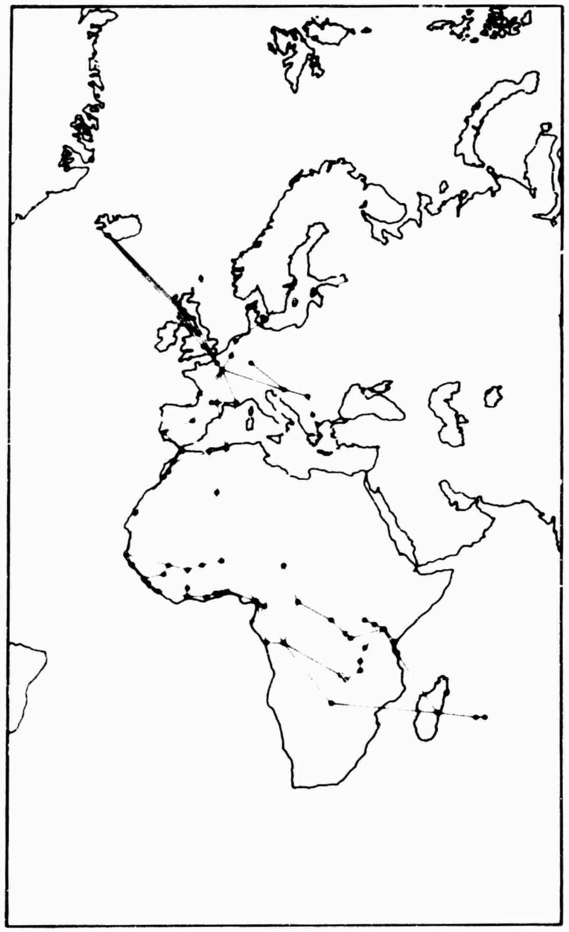


Fig. 19 : Gravimeter ties made by E P F and O R S T O M

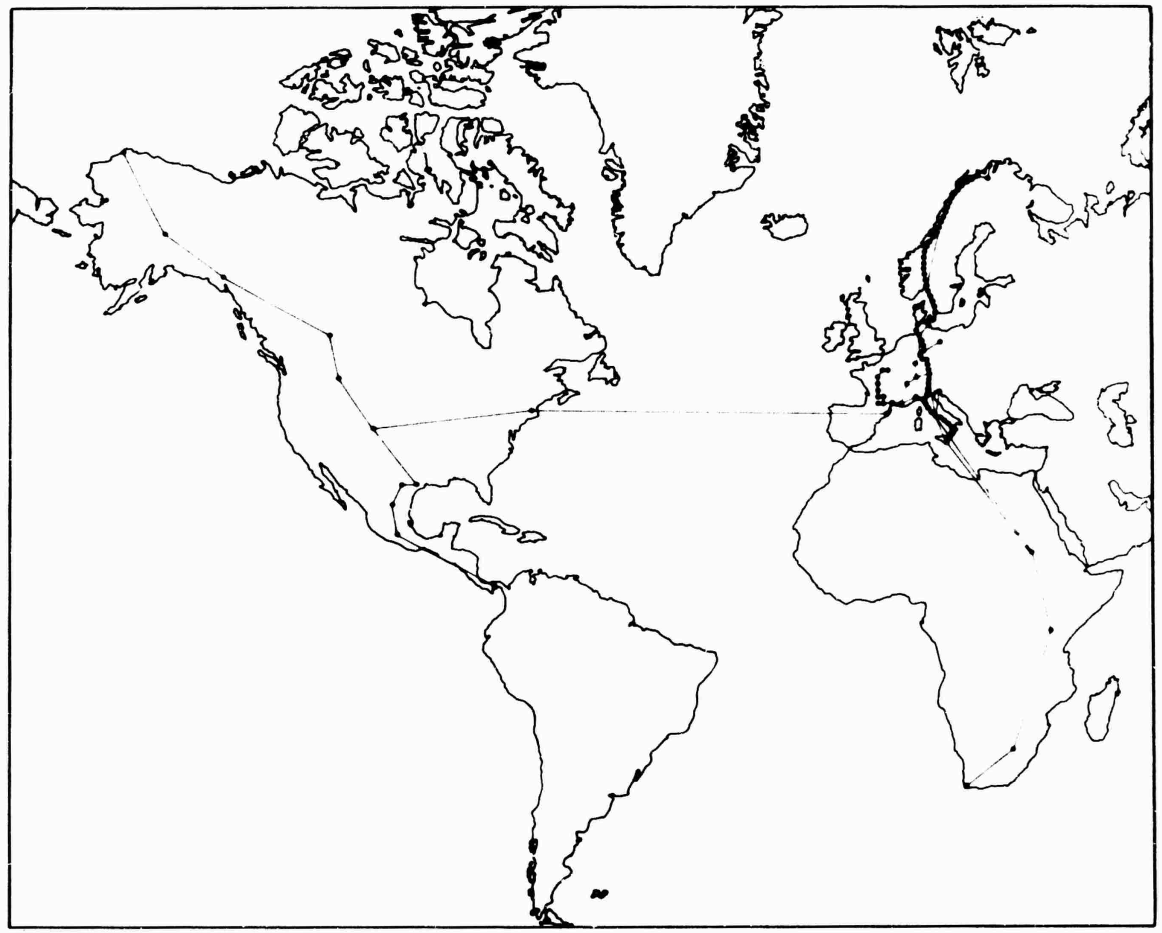


Fig. 20 : Gravimeter ties made by O G S T

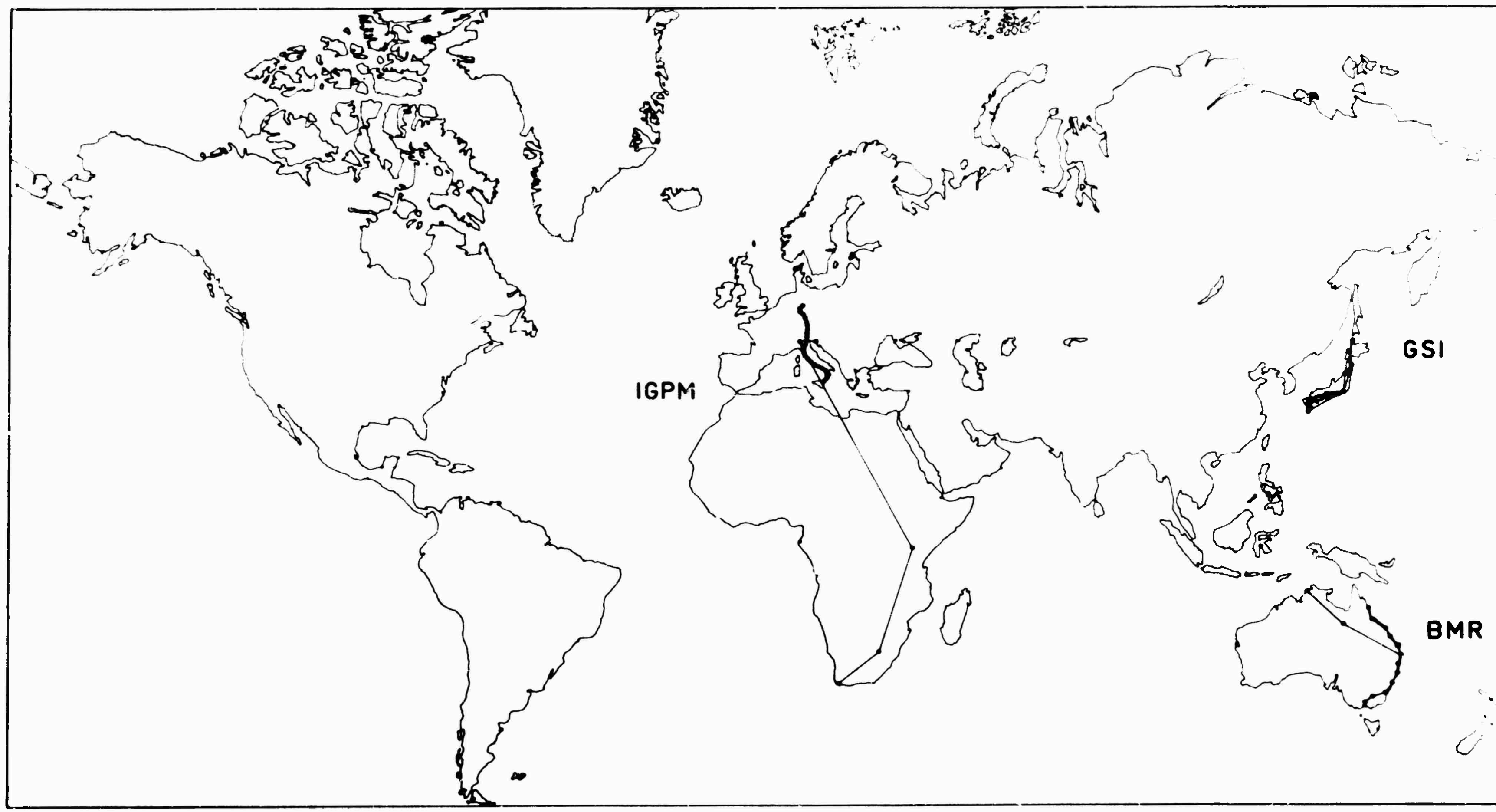


Fig. 21 : Gravimeter ties made by I G P M , G S I and B M R

3.2.18. Trips performed by the Osservatorio Geofisico Sperimentale, Trieste *(Figure 20).*

Agency Code 60.

Trip code	Year	Day	GVMTRS	Area
6001	63	46 - 58	L007 , L009	ECL, Italy, detail
6002	63	130 - 219	L803, L807, L002	EACL, Europe
6003	63	296 - 310	L803, L002, L054	EACL, Africa
6004	64	15 - 17	L803, L002, L054	Trieste - Rome - Boston
6050	53		W050, W052	Europe
6051	56		W050, WXP1	ECL Flensburg - Munich detail
6052	57		W050, WXP1	Paris - Bagneres
6053	58 / 59		W050, W052, W203, WXP1	ECL Bad Harzburg - Rome
same			W050, W052, W203, WXP1	ECL Rome - Etna
6054	60		W050, WP74, W485	ECL Mantova - Catania
6055	62		W302, W052, W362 W544, W643	ECL Bad Harzburg - Bodo
0801	64	58 - 85	L054	ACL Panama North

The data have been extracted from published papers (Gantar, Morelli, 1959 and 1962; Gantar 1959; Solaini et al. 1961) or from the data files existing at the OGST, Trieste. Trip 6002 has been made in cooperation with AFCRL.

3.2.19. Trips performed by the Istituto di Geodesia, Topografia e Fotogrammetria del Politecnico, Milano *(Figure 21).*

Agency Code 61.

Trip code	Year	Day	GVMTRS	Area
6101	63 / 64	319 / 9	L002	EACL Africa
6151	58		E048, W053, W116	ECL Bad Harzburg - Catania

The data concerning the trip 6101 have been communicated by Dr. V. Tommelleri; those of the trip 6151 have been extracted from a published paper (Solaini et al., 1961).

3.2.20. Trips performed by the Geographical Survey Institute, Tokyo *(Figure 21).*

Agency Code 90.

Trip code	Year	Day	GVMTRS	Area
9001	63	140 - 151	L004 , L029	WPCL Japan
9002	64	184 - 224	L019, L024, L029, L055, L069	WPCL Japan

The data have been communicated by Prof. Y. Harada, GSI, Tokyo.

3.2.21 Trip performed by the Bureau of Mineral Resources, Melbourne *(Figure 21).*

Agency Code 93.

Trip code	Year	Day	GVMTR	Area
9301	65	31 - 51	L020	WPCL Australia

The data have been communicated by Mr. C. T. Whalen, 1GSSq, Cheyenne.

4. – COMPUTATION AND PREPARATION OF THE DATA

4.1. General Information

The raw data collected and coded for the adjustment of the IGSN 71 and described in the previous sections, consist of the following numerical values :

(a) absolute g values at the observation sites;

(b) corrected half-periods for pendulum measurements at the actual pendulum station sites;

(c) time and reading of the LCR gravimeter observations at the actual station sites; and

(d) gravity differences observed with non-LCR gravimeters.

4.2. Station Coding

A problem arose during the data collection phase with the identification and coding of the station sites. A revision of the previously published catalogues (Coron, 1956; Coron, Monnet, 1959; Morelli et al., 1965) was therefore made and kept updated through continuous contacts with the cooperating agencies for the IGSN 71.

The designation for each primary station has been computed from its geographical co-ordinates according to the IGB coding system (BGI, 1963). To facilitate computer processing of the IGSN 71 data excentre stations have been assigned the same IGB number as the corresponding primary regardless of the excentre station co-ordinates. There are two versions of the set of primary stations; the first version considers one primary site in every city, the second version assumes only one primary site in each one-degree square identified by the five digit IGB number. The total number of primary and excentre sites considered initially for the IGSN 71 was 2040. Some of these sites are observed only by pendulums and therefore will not appear in the final IGSN 71 adjustment.

4.3. Data Reduction

Standard data reduction procedures have been used throughout. Earth tide corrections computed from Longman's formulae (Longman, 1959) have been applied to all measurements. Since the tidal corrections obtained from those formulae do not average to zero at every latitude, Honkasalo (1964) computed an additional correction to account for the permanent low tide at the pole and high tide at the equator. This term, called the "Honkasalo Correction" is computed

$$\text{as} \quad C_{\ell_s} = - 0.037 \ (1 - 3 \sin^2 \phi) \ \text{mGal}$$

where ϕ is the station latitude.

It is added to the tidal correction computed from Longman's formulae.

The corrections which have been applied to each type of measurement listed in section 4.1. are given below :

(a) Absolute g values given by the various observers generally include all necessary corrections for systematic effects. The Honkasalo correction has been applied.

(b) Gravity differences have been computed from the corrected pendulum periods, as supplied by the individual observers, using the approximate g values from preliminary adjustments of the IGSN 71 data on absolute datum. Older Cambridge pendulum observations were recomputed with new temperature correction formulae determined by Honkasalo in 1963 to be consistent with the more recent measurements. The Honkasalo correction has been applied.

(c) LaCoste and Romberg gravimeter observations have been reduced using the manufacturer's dial calibration tables, pseudo-periodic screw error corrections (Whalen, 1966a) for LCR 7, 9, 43, 44, 47 and 48 only and pressure corrections (Data Reduction Division, 1381st GSS, 1963) for LCR 44 only. Earth tide corrections are applied to all LCR measurements but the Honkasalo term has not been applied since it is nearly linear over the range of the gravimeter observations.

(d) Non-LCR gravimeter gravity differences are used as reduced by the original observers. No further corrections have been applied.

4.4. Data Preparation Procedure

The data collected by OGST for the IGSN 71 adjustment was collated and edited using the computing system given in Fig. 22. The work was carried out using the IBM 7044 computer at the University of Trieste. Following the generation of the final data files, the observations were run through program ADJUST having a maximum solving capability of 150 unknowns, fixing g values at key stations and considering a different group of trips in each run. This cumulative editing, which required 20 different adjustment runs, allowed the identification of gross errors and the determination of preliminary scale factors required for the adjustment of the excentre nets. These scale factors appeared to agree within ± 1 part in 20,000 in most cases with those obtained from earlier adjustments performed on selected nets by other members of the Sub-Group. The scale uncertainty in the excentre adjustments was therefore considered negligible for the purposes of the preliminary investigations of the IGSN 71. The reduction of the ties to primary sites is made by means of the centering corrections (Section 4.2.) computed by adjustment of some 10,000 "local" ties observed during the course of the long range measurements integrated with about 4,200 ties taken from other sources.

Three versions of input data have been prepared to facilitate the various stages of the analysis and to satisfy the computing system requirements of individual members of the *Working Sub-Group*:

(i) uncentred data;

(ii) data centred to cities; and

(iii) data centred to IGB squares.

The data files prepared are shown in *Figure 22*.

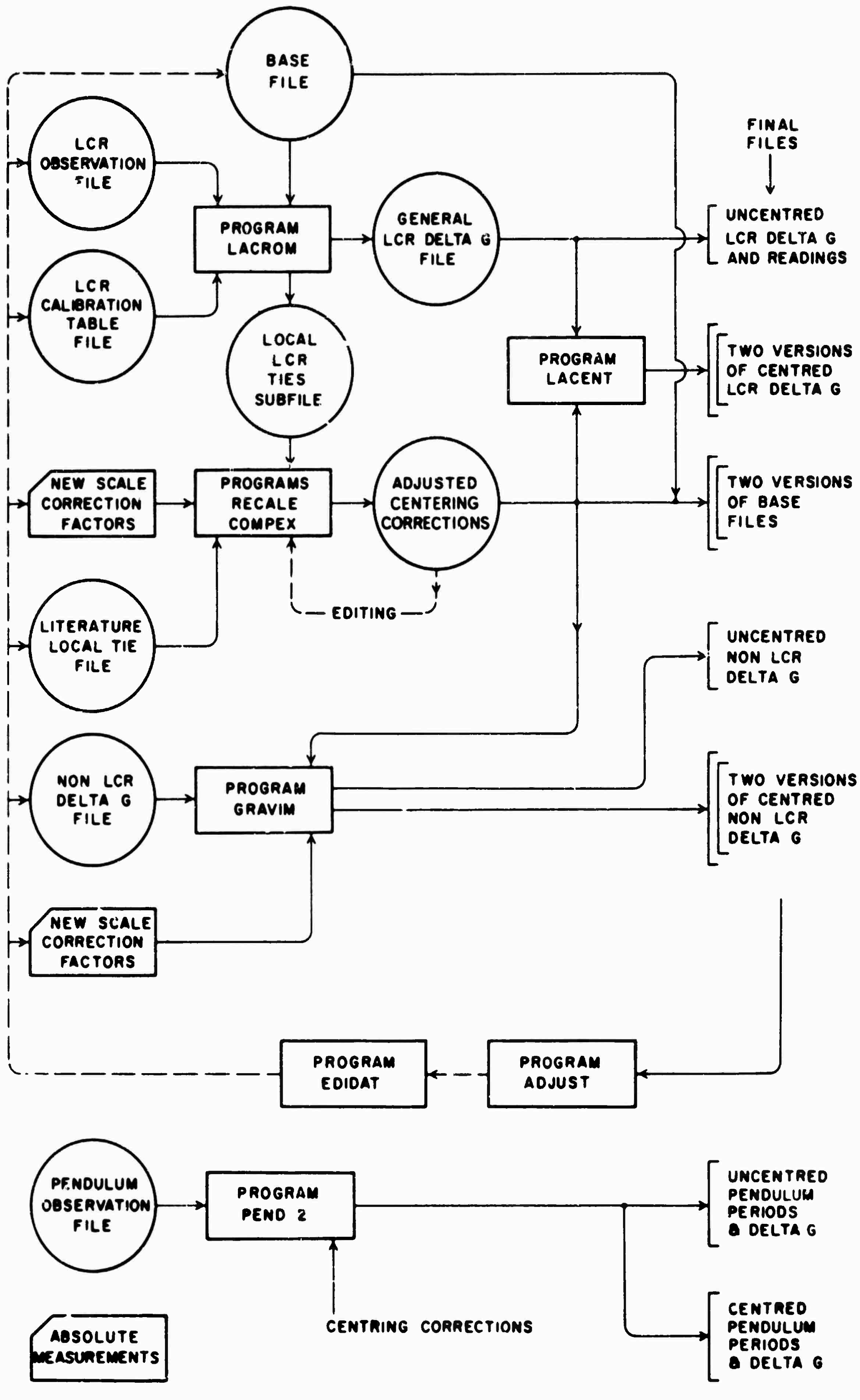


Fig. 22 : Flow Chart for the Preparation of Data

APPENDIX II

ADJUSTMENTS AND ANALYSES OF DATA FOR IGSN 71

Performed at Ohio State University

Columbus, Ohio, U.S.A.

by

Urho A. Uotila

Department of Geodetic Science

 Preceding page blank

TABLE OF CONTENTS

1. – INTRODUCTION

The scientists at the Ohio State University have been interested in the gravity field of the Earth for a long time. We have made several adjustments of world-wide reference base nets in the past in order to use gravity data for geodetic computations. Because of our interest in the past, we welcomed the opportunity to participate in this phase of work of Special Study Group 5. Furthermore, at the Bedford meeting in 1967, it was felt that a contribution could be made to the international effort by using a somewhat different approach to the problem that the others were planning to use.

2. – DATA

Detailed description of the available data for the adjustment is given in Appendix I.

3. – MATHEMATICAL MODELS FOR THE ADJUSTMENT

This section describes the basic mathematical model from which the observation equations are derived.

The general form of a mathematical model is :

$$F\,(X^a\,,\,L^a) = 0 \tag{1}$$

where

X^a = theoretical or adjusted values of parameters,

L^a = theoretical or adjusted values of quantities to be observed or that have been observed.

The unusual minimum variance solution for the model expressed by equation (1) in matrix notation is :

$$\delta X = -\,(A'\,(BP^{-1}\,B')^{-1}\,A)^{-1}\,A'\,(BP^{-1}\,B')^{-1}\,W \tag{2}$$

where

$$A = \left.\frac{\partial F}{\partial X^a}\right|_{X^a = X^o} \;;\quad B = \left.\frac{\partial F}{\partial L^a}\right|_{L^a = L^b} \;;\quad W = F\,(L^b\,,\,X^o)$$

$P^{-1} = \Sigma_{L^b}$ = variance-covariance matrix of observed quantities.

L^b = observed quantities, X^o = approximate values of parameters.

Estimates, i.e. adjusted values for the parameters are obtained as follows :

$$X^a = X^o + \delta X \tag{3}$$

Variance-covariance matrix of parameters has the form :

$$\Sigma_{X^a} = (A'\,(BP^{-1}\,B')^{-1}\,A)^{-1} \tag{4}$$

3.1. Gravimeter Measurements

In the case of gravimeter observations the most general equation for one gravity difference is :

$$d_i^a - d_j^a + k^a (t_i - t_j) + \ell^a (d_i^a - d_j^a) + m^a (d_i^{a^2} - d_j^{a^2}) \tag{5}$$

$$+ n^a (d_i^{a^3} - d_j^{a^3}) - (g_i^a - g_j^a) = 0$$

where

d_i , d_j = dial readings in mGal at the stations i and j, respectively, corrected for all known systematic effects.

k = coefficient for drift.

t_i , t_j = time of observation of the dial readings at stations i and j, respectively.

ℓ = coefficient for a linear scale factor term.

m = coefficient for a second order scale factor term.

n = coefficient for a third order scale factor term.

g_i , g_j = gravity values at the stations i and j, respectively.

a = superscript indicating theoretical or adjusted value.

Theoretically, there are as many equations as the number of observed gravity differences plus the number of sequentially repeated readings at the same station. For each gravimeter there are one or more drift rates, k, and one or more corrections, ℓ , to the original linear calibration factor, and one or more coefficients, n and m, for the second and the third order scale factor terms, respectively, but there is only one g_i for station i, $i = 1, 2, \ldots, u$, where u is the number of gravity stations included in the adjustment.

A family of mathematical models can be derived from equation (5) by omitting some of the coefficients which might not be statistically significant or which cannot be physically justified. The k's (drift rates) may sometimes belong to the first category; the coefficients for the second and third order scale factor may belong to the second category.

In the actual observation equation the term $(g_i^a - g_j^a)$ from equation (5) sometimes is replaced by :

$$(g_r^a - \Delta g_{ri} - g_s^a + \Delta g_{sj})$$

where g_r, g_s are gravity values at the stations r and s which are excenters of i and j respectively, and where $\Delta g_{ri} = g_r - g_i$ and $\Delta g_{sj} = g_s - g_j$. These gravity differences are taken as fixed quantities obtained from local adjustments performed at OGST and distributed for final adjustments (see Appendix 1) or from Whalen's or our own preliminary adjustments.

All included LaCoste - Romberg dial readings were changes to milligal readings using conversion tables and corrected for usual tidal and Honkasalo effects before adjustment.

In the linearized form our equations are in the matrix notations :

$$A\ \delta X + BV + W = 0 \tag{6}$$

where the matrices are those defined earlier.

The second type of approach for solving the parameters given in equation (5) is to use derived gravity differences as observed quantities, e.g., $d_i^b - d_j^b = \Delta^b g_{ij}$. This may be used when m and n are not included as unknowns. In this case we can write a mathematical model :

$$\Delta g_{ij}^a + k_\cdot^a (t_i - t_j) - \ell^a \ \Delta g_{ij}^a - g_i^a + g_j^a = 0 \qquad (7)$$

where Δg_{ij}^a = adjusted value of observed gravity difference between station i and j. Other quantities are defined previously.

If the coefficients of the parameters in the set of the above equations form the A matrix and P^{-1} is the variance-covariance matrix of gravity differences computed from observations and $w_{ij} = g_i^o - g_j^o - \Delta^b g_{ij}$ is an element of W_1 matrix where :

g_i^o , g_j^o = approximate gravity values for stations i and j respectively and

$\Delta^b g_{ij}$ = observed gravity differences between stations i and j,

the observation equations in matrix form are :

$$V = A \ \delta X + W_1 \qquad (8)$$

The solution vector for the minimum variance solution is :

$$\delta X = - (A' \ PA)^{-1} \ A' \ PW_1 \qquad (9)$$

and the variance-covariance matrix of parameters is :

$$\Sigma_X = (A' \ PA)^{-1} \qquad (10)$$

The expected value for the variance of unit weight is one.

By comparing equations (2) and (9) we can conclude that these solutions differ from each other only when one observed dial reading has been used in the computations of two gravity differences. For example, when we have observed dial readings d_i^b , d_j^b , d_k^b and have computed $\Delta^b g_{ij} = d_i^b - d_j^b$ and $\Delta g_{jk}^b = d_j^b - d_k^b$, dial reading d_j^b has been used in both computations. Therefore in equation (9) we neglect existing correlation between $\Delta^b g_{ij}$ and $\Delta^b g_{jk}$.

Because the mathematical model as expressed by equation (5) is theoretically more correct in our case than the model as expressed by equation (7), we will use equation (5) in our computations.

When selecting the mathematical model expressed by equation (5) it becomes obvious that only those gravimeter observations can be used for which dial readings were available, i.e. only LaCoste - Romberg type observations were used.

It is easy to recognize that we cannot solve for δX as given in equations (2) from observation of dial readings alone without additional observations of other quantities which would give us the reference level of the network and scales for the gravimeters. This information can be provided by several absolute measurements of gravity or by one measurement of absolute gravity and a series of relative pendulum observations or a combination of the above two.

3.2. Absolute Measurements

If we have only one absolute measurement available, we can impose a condition which holds this station at a given value; the scale may then be obtained from relative pendulum measurements. When we have more than one absolute measurement, we have the following mathematical model for each absolute measurement :

$$c_i^a - g_i^a = 0 \tag{11}$$

where c_i^a is the adjusted value of the absolute measurement at i^{th} station. The other quantity has been defined earlier.

The absolute measurements can be added to equation (2) in the following way :

$$\delta X = -(A'(BP^{-1}B')^{-1}A + P_x)^{-1}(A'(BP^{-1}B')^{-1}W - P_x W_g) \tag{12}$$

where dimensions of P_x are the same as $A'(BP^{-1}B')^{-1}A$ or u x u when the dimensions of X are u x 1, and all other elements are zero except those diagonal elements which correspond to the corrections to the g_i for the absolute station i. The non-zero diagonal element, Px_{ii}, is $\frac{1}{\sigma^2_{x_i}}$, i.e., the reciprocal of the variance of the absolute measurement at the i^{th} station.

The corresponding w_G, element is :

$$w_G = c_i^b - g_i^o \tag{13}$$

All other elements of W_G are zero except those corresponding to absolute sites.

3.3. Pendulum Measurements

For the adjustment of pendulum data, we used two different mathematical models. For preliminary adjustment we used the general formulas :

$$(g_r^a - \Delta g_{ri}) \frac{\left\{T_i^a + k^a (t_i - t_o)^2\right\}}{\left\{T_j^a + k^a (t_j - t_o)^2\right\}} - (g_s^a - \Delta g_{sj}) = 0 \tag{17}$$

and

$$T_{i1}^a + k^a (t_{i1} - t_o) - T_{i2}^a - k^a (t_{i2} - t_o) = 0 \tag{18}$$

where, in the first equation g_r^a and g_s^a = theoretical or adjusted gravity values at stations r and s respectively, T_i and T_j = theoretical or adjusted swinging times of a pendulum at stations i and j respectively, k^a = theoretical or adjusted value of a drift rate for a pendulum during a trip, t_i and t_j = the time of observations at stations i and j, t_0 is some initial time (t is considered errorless in adjustment). Δg_{ri} and Δg_{sj} as defined earlier.

The second mathematical model used is similar to the model expressed by equation (7). For each gravity difference measured with a pendulum, we used :

$$\Delta g_{ij}^{a} + k^{a} (t_j - t_i) - g_i^{a} + g_j^{a} = 0 \tag{19}$$

or

$$\Delta g_{ij}^{a} + k^{a} (t_j - t_i) - g_r^{a} + \Delta g_{ri} + g_s^{a} - \Delta g_{sj} = 0 \tag{20}$$

All other notations are as defined earlier, except Δg_{ij}^{a}, which is the theoretical or adjusted gravity difference between stations i and j as computed from theoretical or adjusted pendulum swinging times.

4. – ANALYSIS FOR A PRIORI VARIANCES OF OBSERVATIONS

In order to have a realistic weighting system in the least squares adjustment the a priori variance of each observation should be determined. In the case of correlated observations an attempt should be made to determine appropriate covariances. When the variance-covariance matrix of observations is available its inverse may be used as the weight matrix without modification.

4.1. Gravimeter data

After samples of gravimeter data were received, we started analysis for variances of observations. Even though we had decided to use dial readings as observations, we felt that it was easier to start analysis of variances for gravity differences computed from the dial readings and then in proper time, to convert these variances to correspond to the dial readings. At first glance, the data indicated that there were several large discrepancies in measurements, mostly caused by tares in gravimeters. In order to eliminate the connections affected by tares and possible blunders, we computed mean differences between stations and estimated variances in groups. Before estimating sample variances for each individual instrument, we wanted to get the blunders out; therefore, we pooled all sample variances in subgroups which were formed as a function of size of gravity differences. *Table 1* gives the results of the analysis.

Table 1

Preliminary Analysis of Standard Errors

Gravity Differences in mGal	Number of intervals	Number of Residuals	Standard Deviation
0 - 1	642	5082	0.043
1 - 5	203	1443	0.030
5 - 50	401	2875	0.039
50 - 100	182	1199	0.056
100 - 200	153	1159	0.058
200 - 300	79	559	0.075
300 - 400	64	519	0.096
400 - 500	33	308	0.091
500 - 1000	76	554	0.113
> 1000	23	158	0.228

The results of the above analysis were used to establish a preliminary rejection criteria. We tentatively adopted the following rejection limits :

Table 2

Preliminary Rejection Limits

Gravity Differences in mGal	Difference from Mean in mGal
< 100	0.18
100 - 500	0.24
500 - 1000	0.40
> 1000	0.60

The limit increases as the gravity differences in mGal increases. This was caused partly by errors in the calibrations which had not yet been computed. The above limits for rejections were to be used before the first analyses of variances for each instrument. After more statistical analysis has been done, a second look for the rejection criteria was planned to be made. Using the above rejection criteria, we had to reject 227 from about 14 000 gravity intervals. Tentative analysis showed that only 12 of them were reading blunders. The others were jumps or tares; 109 measurements differed more than 1 mGal from the mean.

After deleting the above-mentioned connections and readings, we performed several adjustments instrument by instrument and trip by trip and finally one tentative combined adjustment was made using sample variances obtained from earlier partial adjustments in weighting of each gravimeter dial reading. After obtaining more complete data set of gravimeter readings during Spring 1970, we re-analyzed sample variances for each instrument.

When combined adjustment of gravimeter data and absolute measurements was made, the sample variance of unit weight became about 3 even though the expected value was one. Re-examination of the weights determined for each gravimeter was made using residuals obtained from the adjustment. 95 % confidence intervals were established for the sample variance obtained for each instrument. If original estimated sample variance was in the interval, no change was made to the earlier estimate. In the case that the earlier estimate was outside of the interval, a new variance was assigned for the instrument taking the closest border value of the confidence interval as a new variance for the instrument. A new adjustment was made with the new weights. The largest differences in parameters were about 0.02 mGal but the variance of unit weight became 0.950. The above procedure was repeated. There were no significant changes in the values of the parameters but the sample variance of unit weight became 1.005. In all of these variations, only limited number of gravimeters received a new variance.

4.2. Pendulum data

Variance for swinging times of various pendulums were obtained through adjustment of observed data for each pendulum separately. Adjustments were made trip by trip for each instrument and obtained sample variances for each instrument were found to be equal to 95 % confidence level and therefore were pooled; only two variances, as a maximum, were obtained for each instrument.

When gravity differences were used in the final adjustment instead of swinging times, a new set of variances was computed. In this case, observed gravity differences with pendulums were compared to those gravity differences obtained from the combined adjustment of gravimeter data and absolute measurements. For each pendulum a variance was computed for each trip. After examining that the variance at 95 % confidence level could have been equal for each trip, only maximum of two pooled variances were computed for each pendulum set; one for observations made before 1960 and the second one for observations made after 1960.

4.3. Absolute data

The variances given by observers were used in the determination of weights for these measurements with one modification. The variances used are given in Appendix I of this report.

5. – ADJUSTMENT OF DATA

As it has been explained above, several tentative and partial adjustments were made in order to evaluate variances for weighting purposes. The examination of the equations (5), (11) and (17) to (20) reveals that the meaningful adjustments would be :

1. Combination of gravimeter data and absolute measurements.

2. Combination of gravimeter data and pendulum data with one gravity station with fixed gravity value.

3. Combination of gravimeter data and absolute measurements and pendulum data.

There can be several variations of the three main systems depending upon which unknowns are included in the mathematical model expressed by equation (5). We have to realize that it is not feasible to adjust gravimeter data alone with one fixed station because the scale factors of the instruments are unknown.

5.1. Preliminary adjustment

The first meaningful adjustment was performed in 1970 in which a mathematical model expressed by equation (5) was used for gravimeter measurements without m and n parameters, one expressed by equation (11) for absolute measurements.

It is expected that if the scale of the network is controlled by absolute measurements the largest contribution for the scale comes from the absolute measurements which have the largest gravity difference between them. In this particular case, the extreme stations are in Fairbanks and Bogota, having a gravity difference of 4900 mGal between them. In order to check on the consistency of the absolute measurements one adjustment was run without including absolute measurements at Fairbanks and Bogota. After their removal, the largest gravity difference between absolute sites was about 1600 mGal. The comparison of the results of these two adjustments, one with all absolute measurements included, (adjustment no. 1), the other without absolute measurements at Fairbanks and Bogota, (adjustment no. 2), showed about 0.06 mGal or better agreement everywhere, including these two above-mentioned absolute sites. Differences at the absolute sites are given in *Table 3*. This comparison suggests that absolute measurements are consistent and standard deviations given for them seem to be realistic.

Table 3

Differences between Adj. no. 1 and Adj. no. 2

	mGal
Bogota	+ 0.041
Washington	- 0.007
Denver	+ 0.001
Boston	- 0.012
Paris	- 0.011
Teddington	- 0.019
Fairbanks	- 0.051

We ran a third adjustment in which we combined gravimeter and pendulum data with absolute measurements. Pendulum data was included using the mathematical models described by equations (17) and (18). We found some systematic difference between this adjustment and adjustment no. 1. More detailed analysis suggested that it might be wiser at this time to use the models described by equations (19) and (20) in the later adjustments.

5.2. Final adjustments

All the necessary data for the final adjustment was received in March, 1971. After twenty five preliminary adjustments and several analyses of the data, final adjustments were started. Drawing from the experience which we have gained during preliminary adjustments, more automated data treatment was worked out.

5.2.1. Rejection limits

One of the difficult problems was to establish rejection limits especially for gravimeter measurements. This was especially difficult because unpredictable tares could have any size from 0.05 mGal to 10 mGal or more. The smaller tares for gravimeter observations were difficult to recognize. Our rejection procedure was as follows : computing gravity differences from observed dial readings and correcting these with previously computed scale factors we compared this result with the gravity difference obtained from an earlier adjustment. Allowable difference between these gravity differences was computed from the formula :

$$\text{Rej. limit} = 2.58 \sqrt{\Delta g_{ij}^2 \ \sigma_k^2 + 2 \sigma_d^2}$$

where σ_k^2 is variance for the calibration factor for the instrument in question, σ_d^2 is the variance of dial reading of the instrument. If there were a tare during transportation or blunder in an observation, this system will eliminate equations in question, but not necessarily either of the dial readings. Running through the original data, about 500 connections were omitted out of about 13000. We did not count how many observations were eliminated this way, if any.

5.2.2. Solutions

The selection of the stations to be included in the adjustment was made taking into account the distribution of the stations as well as how many times the site had been occupied. If at a location there were several excentric stations, the A (primary station) was not necessarily selected as an unknown in the solution but the site which had the most outside ties to the other stations (excluding excenter ties). This selection method assured us that the errors in excenter ties had the least effect on the adjustment.

In the final solutions we had 372 stations included as unknowns and we did the following solutions using variations of the mathematical models expressed by equations (5), (11), (19), (20) and various combinations of observed data :

no. 1. Gravimeter data and absolute measurements.

There were three different variations depending upon which coefficients of scale factor terms for gravimeters were solved in equation (5).

A. Solved for coefficients for linear scale factor terms.

B. Solved for coefficients for linear and the second order scale factor terms.

C. Solved for coefficients for linear, the second order and the third order scale factor terms.

no. 2. Gravimeter data, absolute measurements and pendulum data.

A . Solved for coefficients for linear scale factor terms for gravimeters.

B . Solved for coefficients for linear and the second order scale factor terms for gravimeters.

no. 3. Gravimeter data and pendulum data.

One gravity station - Bad Harzburg - was fixed.

Solved for coefficients for linear scale factor terms for gravimeters.

no. 4. Pendulum data alone.

Solved for pendulum stations only.

The above list shows a total of seven different solutions. In each one, except in case no. 4, we solved gravity values for 372 gravity stations.

6. – ANALYSIS OF THE RESULTS

After the adjustments, variances of unit weights were computed. As it is known, the expected values for variance of unit weight is 1 under the used weighting system. The results for the various solutions are given in *Table 4.*

Table 4

Samples of A Posteriori Variances of Unit Weight

Solution	Degree of Freedom	$\hat{\sigma}^2$
1A	7339	1.005
1B	7281	0.938
2A	8356	1.020
2B	8298	0.962
4	914	920

According to Fischer's F-test, the coefficients for the second order scale terms were highly significant at 5 % significance level and at the same level also, the coefficients for the third order scale factor terms were significant; however, when physical facts, such as the distribution of absolute sites, are taken into consideration, it is difficult to justify these correction terms and their sizes to individual gravimeters at this time. In the future, more investigations should be done in this area, especially, observations should be done along a calibration line and care should be taken that no tares occur between the stations. Under these circumstances, possibly, the significance of the second and higher order terms could be more definitely determined. It would be helpful to add some more absolute sites along the calibration lines in order to control these terms better. It is interesting to note that the second order terms from the solutions 1B and 2B were generally in agreement.

It should also be noted that drift unknowns for LaCoste-Romberg gravimeters were not significant at the 5 % significance level. Therefore, the "observed" drift in some instruments might be caused by small tares rather than regular drift of the instrument.

The gravity values of the stations, as obtained from various solutions may be compared through a series of graphs. We computed differences at all stations between the adjusted values of gravity coming from any two solutions. We plotted these differences as a function of gravity value of the station. Four different graphs were made for each set of differences (total 28).

(a) For the whole world

(b) For the North American Calibration line

(c) For the Euro-African Calibration line

(d) For the Western Pacific Calibration line.

Samples of (a) are given in *Figures 1–4* and their closer examination suggests the following :

(1) There were no significant differences between the graphs for the whole world and the corresponding ones for the individual calibration lines.

(2) Differences between solution 1A and 2A (*Figure 1*) are small, but systematic in nature. This suggests that pendulum observations had an effect on the scale, but the difference is only about 1 part in 90 000 which is relatively small in comparison to the expected accuracy in scale, which has been estimated to be between 1/40 000 - 1/50 000 range.

(3) Differences between 1B and 2A as given in *Figure 2* suggest that the second order terms in calibration have systematic effects of a different nature. It is interesting to note that the values in solution 1B agree better with measured absolute values (*Table 5*). If the absolute values were with high accuracy, the solution where the second order terms were included could be considered as a better solution than the one without the term. A better comparison can be made between solutions 2B and 2A. We can see from *Figure 3* that at lower g-values the agreement is very good. It means that the pendulum observations control the second-order correction terms very well except at the stations which have a gravity value larger than Fairbanks.

This indicates that we might need new absolute values at stations with a higher gravity value or more pendulum observations in order to control the second order terms. The comparison of the solved coefficients shows that the first and second order terms for the gravimeters are almost the same in those two solutions. It is too early to draw a conclusion as to whether or not the second order terms for calibration can be determined from the solutions.

(4) Comparison of the results between solutions 3 and 2A shows, *Figure 4*, as expected, the same type of scale difference as between solutions 1A and 2A; but, of course, with opposite signs. The excellent agreement between 1A and 3 at all absolute sites, suggests also that the scale obtained from absolute measurements agrees with scale derived from pendulum measurements. The only major difference is in the absolute value at Bogota, which is somewhat off, by about 0.1 mGal. The examination of absolute measurements at Bogota indicates that there have been problems in observations caused possibly by local seismic activities.

(5) It can be concluded that even though we have several absolute sites in the network and pendulum measurements, the major error source is the uncertainty in scale. This is demonstrated through standard errors computed for all stations and for all gravity differences in the net. Samples of these computations are given in *Table 6*.

Table 5

Comparison of Results

(Diff. in mGal)

Station Name	Int. Code	ABS-2A	1A-2A	1B-2A	2B-2A	3-2A	4-2A
FAIRBANKS *	23147K	-0.023	0.019	-0.018	-0.029	-0.005	0.042
BOSTON *	15221J	0.009	0.000	0.012	0.009	0.006	
MIDDLETOWN *	15212A	-0.012	-0.002	0.009	0.008	0.007	
DENVER *	11994N	0.031	-0.009	-0.001	0.010	0.010	-0.099
WASHINGTON *	11687M	-0.065	-0.003	0.008	0.009	0.008	-0.086
BOGOTA *	844K	-0.126	-0.034	-0.114	-0.031	0.028	0.218
BUENOS AIRES	43848K		-0.011	-0.003	0.009	0.011	0.196
HAMMERFEST	28603A		0.027	-0.025	-0.036	-0.009	-0.256
TEDDINGTON *	18110J	0.078	0.001	-0.002	-0.004	-0.002	0.033
PARIS **	18082O	-0.003	0.001	0.001	-0.001	0.002	0.422
BAD HARZBURG	21510C		0.005	0.002	-0.005	0.000	0.000
NAIROBI	35716N		-0.035	-0.093	-0.013	0.024	0.061
CAPETOWN	46738K		-0.014	-0.011	0.004	0.011	0.161
SINGAPORE	2613A		-0.028	-0.084	-0.025	0.020	0.113
MELBOURNE	45474M		0.000	0.015	0.013	0.008	-0.090

* Absolute station
** Absolute = weighted mean

Table 6

Estimated Standard Errors for Selected Sample Stations and for Computed Gravity Differences between These Stations as Obtained For Adjustment 2A. Units in μGal.

	FAI	BOS	MID	DEN	WAS	BOG	BUE	HAM	TED	PAR	BAD	NAI	CAP	SIN	MEL
FAI	037	038	040	053	044	098	052	027	027	033	026	096	055	086	050
BOS		018	011	018	010	062	020	051	021	018	020	061	024	051	022
MID			020	019	012	061	021	053	024	020	023	060	025	050	023
DEN				026	011	047	014	065	034	028	033	046	018	036	020
WAS					020	056	016	056	025	021	024	053	020	045	020
BOG						067	049	108	077	070	077	021	049	026	056
BUE							027	064	034	029	033	048	018	040	022
HAM								050	010	046	039	106	067	096	062
TED									022	017	014	075	037	066	033
PAR										017	017	069	032	059	029
BAD											022	075	036	065	032
NAI												066	046	024	054
CAP													031	039	024
SIN														057	043
MEL															028

Fai = Fairbanks
Bos = Boston
Mid = Middletown
Den = Denver
Was = Washington
Bog = Bogota
Bue = Buenos Aires
Ham = Hammerfest
Ted = Teddington
Par = Paris
Bad = Bad Harzburg
Nai = Nairobi
Cap = Cape Town
Sin = Singapore
Mel = Melbourne

7. – SUMMARY

From the analysis of various solutions it can be concluded that the scale uncertainty is about 1 part in 40 000 to 1 part in 50 000, and gravity values at individual sites have an accuracy of 0.1 mGal or better. The absolute gravity measurements have been found to be consistent and the scale obtained from absolute measurements is in good agreement with the scale obtained from pendulum measurements. There are all indications that pendulum measurements with gravimeter measurements with one absolute measurement, would have given a good network. Similarly, the absolute measurements with gravimeter measurements would have given a good network, so the combined net can be considered to be highly consistent. The accuracies in the network are of that level that it might be possible to detect changes in gravity as a function of time, therefore, international effort should be directed toward monitoring these changes in order to see if they really exist. In the case that gravity is changing as a function of time, the epoch for gravity values must be established through international cooperation.

8. – ACKNOWLEDGEMENT

The majority of the excentre analyses and computer programming was done by Pentti A. Kärki and the lesser extent was done by Francis Fajemirokun, Peter Morgan and John Gergen.

Extensive computer time used in this study was made available through the Instruction and Research Computer Center of The Ohio State University.

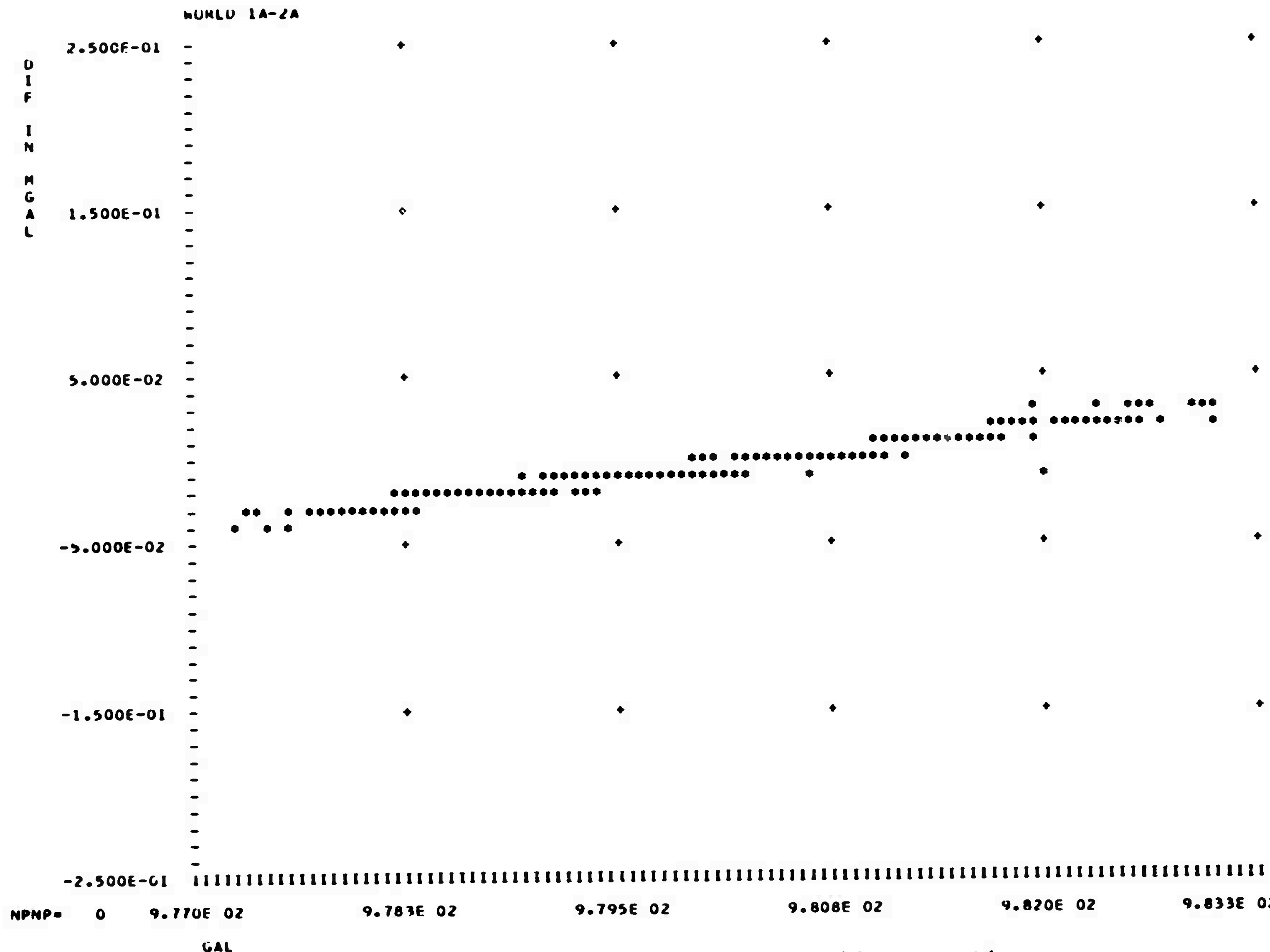


FIG. 1. Comparison between G Values from Adjustment 1A (abs + gvm; linear scale) and 2A (abs + pend + gvm; linear scale)

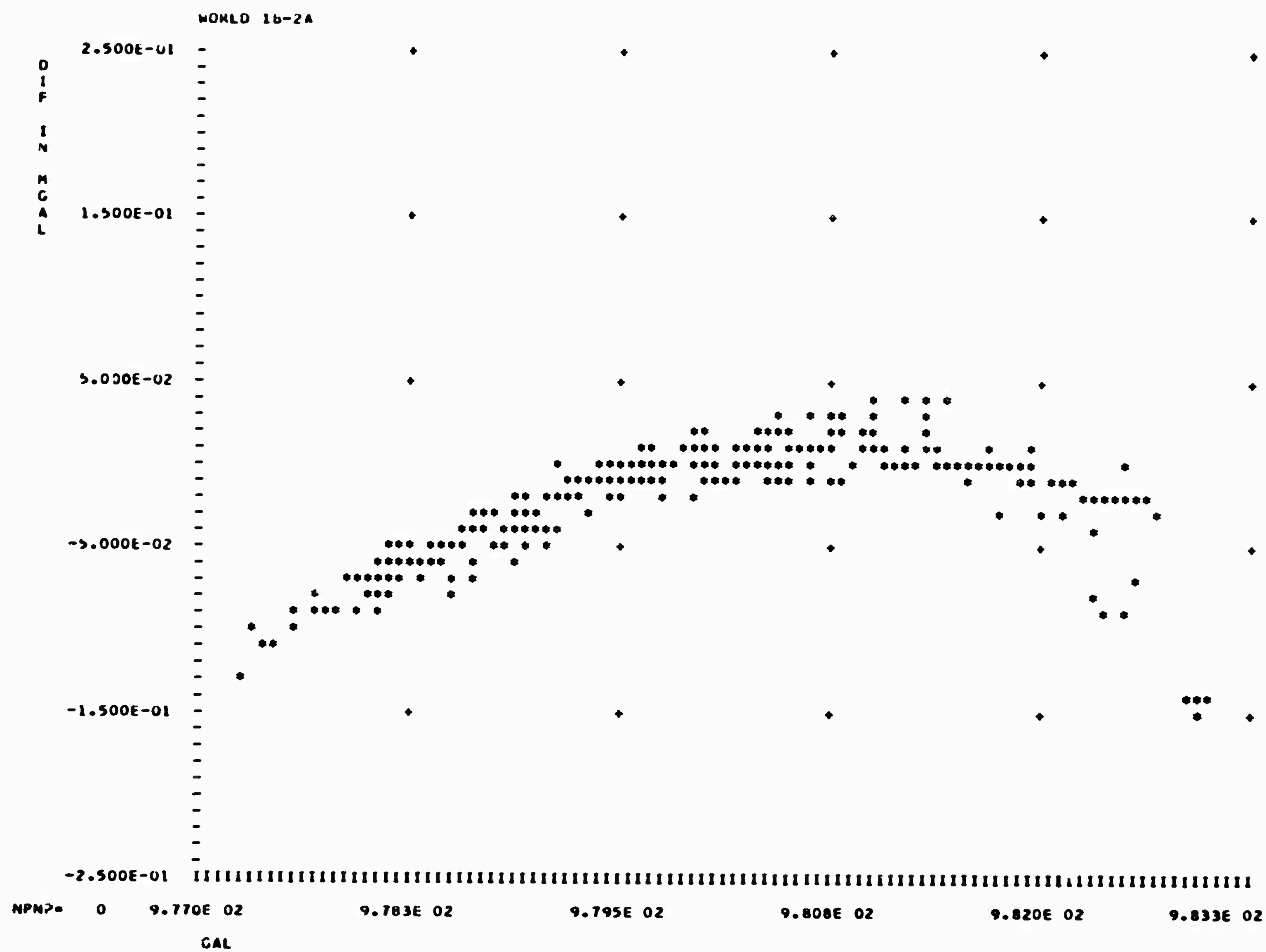


FIG. 2. Comparison between G Values from Adjustment 1B (abs + gvm; second order scale) and 2A (abs + pend + gvm; linear scale)

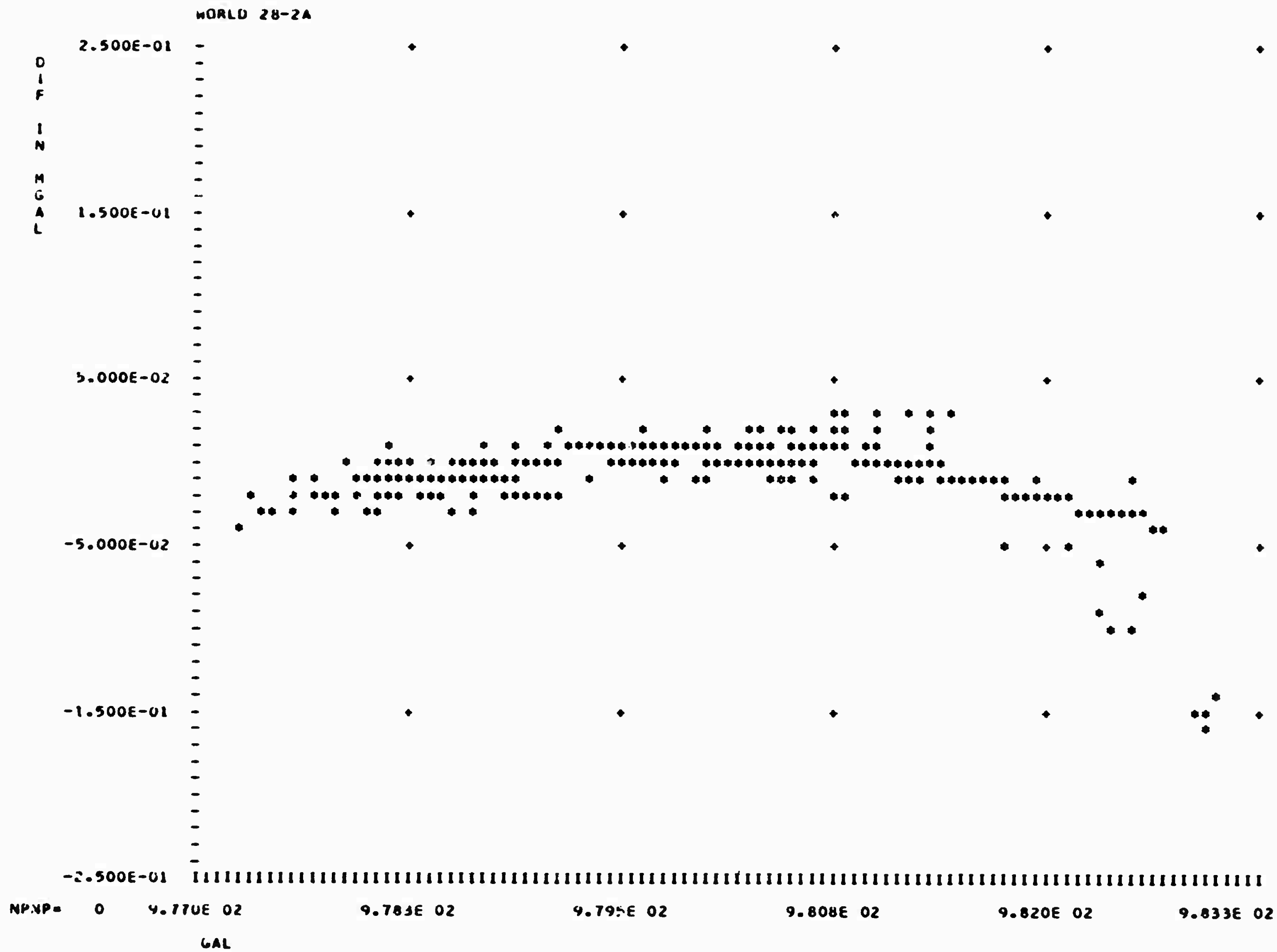


FIG. 3. Comparison between G Values from Adjustment 2B (abs + pend + gvm; second order scale) and 2A (abs + pend + gvm; linear scale)

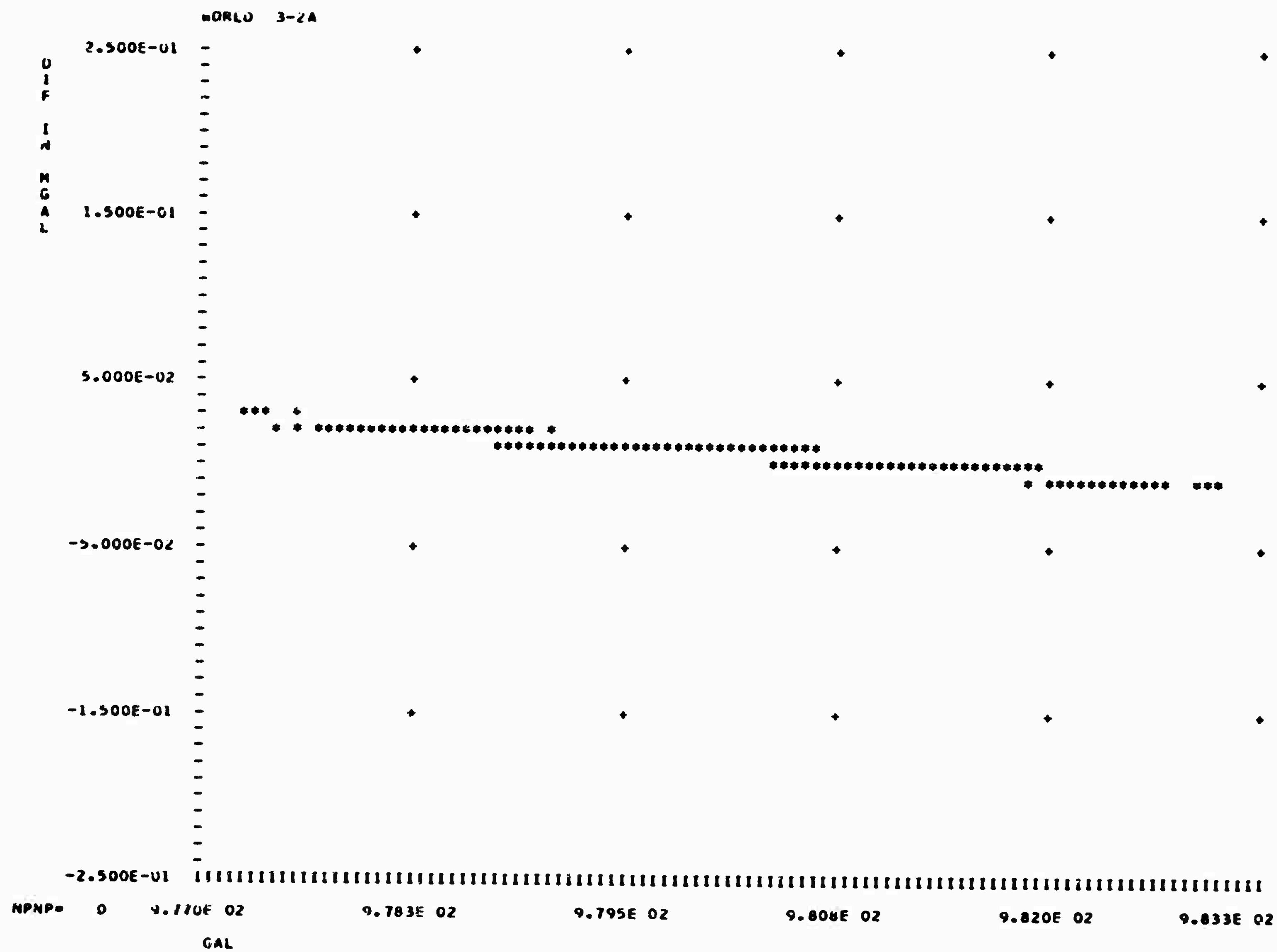


FIG. 4. Comparison between G Values from Adjustment 3 (pend + gvm; linear) and 2A (abs + pend + gvm; linear scale)

APPENDIX III

ADJUSTMENTS AND ANALYSES OF DATA FOR IGSN 71

Performed at 1st Geodetic Survey Squadron

Cheyenne, Wyoming, U.S.A.

by

C.T. WHALEN

United States Air Force
Aerospace Cartographic and Geodetic Service (MAC)

Francis E. WARREN *Air Force Base*

TABLE OF CONTENTS

1. – HISTORICAL BACKGROUND

The writer organized the gravity survey capability of the 1381 GSSq when the squadron was formed in 1959. A review of the gravity base control literature at that time revealed that there was no homogeneous world net in existence.

Between 1959 and 1961 the writer proposed a plan for a world gravity net, coordinated the plan with other interested U.S. organizations and had the plan adopted by the U.S. Air Force.

Five north-south international calibration lines were observed and interconnected to form a homogeneous world net. Observations were made in ladder sequence (ABCDEEDCBA) with a set of four LaCoste Romberg gravimeters. Gravity surveys plans were discussed with SSG 5 at the Berkeley IUGG meeting in 1963. Reports on the five calibration lines are given in Whalen (1965a, 1965b, 1966b, 1966c, 1967a). Requirements for a U.S. national gravity net were identified and a cooperative survey was made by the 1GSSq, TOPOCOM and UW. Results of the surveys were reported in Whalen and Harris (1966) and in Whalen (1967b).

Gravity base net data processing procedures evolved as the above surveys progressed. Woollard's procedures for drift and tare analysis were adopted by the writer for squadron use in 1959. Experience showed that these procedures were not suitable for squadron use.

The data processing problems remained unresolved until Hamilton (1963) showed how gravity base net data from many surveys could be adjusted simultaneously by electronic computer to obtain gravity values and gravimeter scale factors. Hamilton's method was programed for the squadron's CDC PRC 4000 computer in 1963 and 1964. Automatic rejection of bad measurements, linear drift unknowns for pendulums and gravimeters, and statistical analysis features were gradually added to the program.

The 1963 meeting with Hamilton initiated many friendly exchanges of ideas and information on gravity data processing procedures between the EPB and 1GSSq. The writer spent the summer of 1967 in Ottawa working with Hamilton and his colleagues at the EPB on data processing procedures. As a result of this visit many new features were added to the computer programs of the 1GSSq and EPB. In 1969 McConnell and Buck from the EPB joined Zimmerman and Newton from the 1GSSq, and the writer, at the Aerospace Corporation in San Bernadino, California, to again exchange program ideas and to work together on a CDC 6600 computer for several weeks. The gravity base net computer program of the EPB and 1GSSq developed rapidly along parallel lines because of the continued contacts and exchanges of ideas between the two organizations. Capability for larger base net adjustments steadily increased as larger and faster computers became available and as software improved.

The 1GSSq gravity base net data processing system is described in considerable detail below for the information of those who may want to set up a similar system.

2. – DATA PROCESSING SYSTEM

2.1. Work Flow

1GSSq gravity base net data processing work flow is shown in *Figure 1*. Set up data is input to the 1401 on cards at A. The 1401 reads the card data and writes it on a magnetic tape. The magnetic tape data enters the 7094 where it is used to select control information and instrument constants from tape file B, LaCoste-Romberg (LCR) gravimeter readings from tape file C and non-LCR precomputed gravity measurements from tape file D. The data is processed in the 7094, the control file B is updated with improved gravity values and processed data is output on a tape at E for the 1401. The 1401 reads the output tape and writes the ouput information on a line printer.

2.2. Data processing set–up

The set-up instructions for processing data with the IGSSq base net program are given in *Table 1*.

2.2.1. Project Card (Card 1)

The adjustments can be done on one of three datum-scale groups, selectable by codes. Code 01 will provide gravity values on the U.S. National Gravity Base Net Datum and scale. Code 02 will provide gravity values on the Potsdam Datum and on Torge's (1966) scale. Code 03 will provide gravity values on the absolute datum and scale.

If ALL is punched, starting in Column 29, all bases will be treated as primary bases in the adjustment. Gravity values will be determined for each base observed on the survey unless the base is to be held fixed or skipped (see 2.2.3 and 2.2.5 below).

If Column 36 is blank the information shown in the *Table 2* example will be listed for editing purposes. A blank Column 36 is usually used with a 1 in Column 40 to suppress the adjustment. In *Table 2*, READING is in dial units, DH is a correction for instrument height above or below the base, P.C. is a pressure correction for pressure sensitive instruments, CEC is a correction for circular error, and E.T. is the correction for earth tide effects. The READING is changed to mGal units with the table of dial factors, the corrections mentioned above and the correction for the preliminary scale factor (DFSCF) are applied to obtain the corrected reading (C. RDG.). The time interval between readings (T. INT.) is in hours and the reading interval (R. INT.) is in mGal. The base gravity value is usually obtained from the control tape and corrected to the datum code given at the top of *Table 2*. The residual (V) is the difference between the gravity interval obtained from the base gravity values and the reading interval.

If Column 38 is blank, a binary tape will be created containing the information shown in *Table 2*. The tape is used for testing of new models.

A 1 is placed in Column 42 if gravimeter readings are to be input on cards instead of being called from tape file C of *Figure 1*. Readings from new surveys are often input on cards for editing purposes before they are added to tape file C.

2.2.2. Card group 1, gravimeter readings

This card group contains the gravimeter readings when a 1 is placed in Column 42 of the project card.

2.2.3. Card group 2, excluded bases

This group contains the IGB Number and site letter for each base which is not to be included in the data processing. Data is selected for processing by instrument and survey code. The computer will by-pass all readings or measurements at or between bases included in this list. We find it takes fewer input cards to specify what bases not to adjust, within a survey, than it takes to specify what to adjust.

2.2.4. Card group 3, base equivalences

This group contains old and new base designations when base IGB Numbers and site letters are to be changed. This feature is used to temporarily change base designations pending correction of the reading files or to solve for more than one primary base for an IGB Number degree block. In the latter case the left hand digit of the IGB Number is temporarily changed to a 9 for the data processing run.

2.2.5. Card group 4, fixed gravity base values

This group contains the IGB designation of each base whose gravity value is to be fixed in the adjustment. The gravity value and datum-scale code can be punched on the card. If they are not punched on the card, the base gravity value from the control file tape will be fixed. This feature is used to define datum and scale for local surveys in fixing gravity values obtained from previous adjustments.

2.2.6. Card group 5, agency–trip–instrument data

This group contains a card for each agency-trip-instrument combination when the corresponding data will be used in the adjustment. If DRIFT or SCALE are input without equivalences, one drift or scale correction factor will be determined for each agency-trip-instrument. If a drift or correction factor is to be determined based on data from more than one trip, then agency-trip-instrument codes for several trips can all be equivalenced to a common agency-trip-instrument designation.

Preliminary drift and scale correction factors can be input for rejection purposes. Rejections are made between adjustments on $v\sqrt{p}$ values obtained by evaluating the observation equation with preliminary gravity, drift, scale and weight values. The preliminary drift and scale correction factor effects are removed before the adjustment; new correction factors instead of corrections to preliminary values are determined directly in the adjustment.

Weight correction factors are determined as the reciprocal of the variance for the measurement. The variance (VAR) is expressed as a function of the absolute value of the gravity interval measured, with an equation of the form :

$$\mathrm{VAR} = A + BX \tag{1}$$

where A is the constant term, B is the slope and X is the absolute value of the gravity interval.

2.2.7. Card group 6, other gravity measurements

Pre-computed gravity interval measurements and absolute gravity measurements are included in this card group. The absolute gravity measurements are reduced by 980, 000 mGal to fit the format. The 980, 000 mGal are added to the adjusted gravity values before output. This card group was the forerunner of tape file D of *Figure 1*. It was used until the card group grew too for convenient input. Tape file D was created at that time.

2.3. Data Processing

2.3.1. Computation of intervals

Gravimeter readings are obtained from tape file C, *Figure 1*, based on the agency-trip-instrument data discussed in 2. 2. 6. Tables of dial factors and circular error and pressure correction factors (where available and significant) are obtained from tape file B for the gravimeters whose readings were withdrawn from tape file C. Base names, latitude, longitude, elevation and preliminary gravity values are also taken from tape file B for all bases used with the readings from tape file C or with the other gravity measurements from tape file D.

Gravity intervals are computed as discussed in 2. 2. 1. Earth tide corrections were computed using Longman's (1959) equations with a 1. 2 factor to correct for the effect of the elasticity of the earth's surface.

2.3.2. Correction to primary bases

If ALL is not punched on the project card 2.2.1., all gravity intervals observed between IGB degree blocks and all absolute measurements are corrected to the primary base for each block. The primary base is identified by the first site letter appearing with the IGB number for the degree block on the control data on tape file B. The corrections are obtained by taking the difference between the preliminary gravity values for the primary base and the observed base. Two corrections are applied to each gravity interval measured between degree blocks.

2.3.3. Observation equations

The general observation equation used is

$$\sqrt{p_n}\ (-\ C_i + C_j + \mathrm{DFC}\ (\Delta t)_{ij} + \mathrm{SCF}\ (\Delta g/1000)_{ij} + L = v_{ij}) \tag{2}$$

where C_i and C_j are corrections to be determined for preliminary gravity values for bases i and j , DCF is a drift correction factor to be determined, $(\Delta t)_{ij}$ is the time interval in hours for the measurement between bases, SCF is a scale correction factor to be determined, Δg is the observed gravity difference between bases i and j and L is the observed gravity difference minus the difference between the preliminary gravity values from bases i and j, and p_n is the observation weight, the reciprocal of equation (1).

Equation (2) is used for both gravimeter and pendulum measurements. The drift unknowns are deleted if they are not significant. The scale unknowns are used with the pendulum measurements to compare their scales with scale from the absolute measurements. When these scale differences are insignificant, the pendulum scale unknowns can also be deleted from the adjustment.

The observation equation for absolute measurements of gravity takes the form

$$\sqrt{p_n}\ (C_j + L_j = v_j) \tag{3}$$

where L in this case is the observed absolute value of gravity minus the preliminary value, for base j , obtained from tape file B.

2.3.4. Weights

A preliminary weight of 1 is assigned to all LCR measurements computed from tape file C readings. If the time interval for the measurements exceeds 100 hours, the weight is changed to zero. Weights previously assigned to the measurements from tape file D are used as preliminary estimates. These weights are multiplied by the weight correction factors discussed in 2.2.6.

2.3.5. Rejections

Observation equation (2) is evaluated for each gravimeter or pendulum gravity difference, without the C-terms and with preliminary drift and scale factors when significant. Measurements with absolute $v\sqrt{p}$ values exceeding the rejection limit are rejected by assigning a zero weight. Observation equation (3) is solved without the C_j term for absolute measurements.

2.3.6. Normal equations, solution, error terms

System subroutines are used to form the normal equations, solve the normal equations, obtain the standard error of unit weight and the error terms for the corrections to preliminary gravity values, drift rates and scale factors determined in the adjustment. Statistics are also determined which are discussed below. Two programs are available. The first obtains the error terms for the unknowns. The second program is used for editing and does not obtain the error terms for the unknowns.

2.4. Output

2.4.1. Rejected measurements, Table 3

Rejected measurements are listed with corresponding observation equations for use in data analysis. This listing is used to locate such things as bases where excenter problems exist or where preliminary gravity values are in error by more than the rejection limit.

2.4.2. Dependency of variances on interval size, Table 4

The residuals and corresponding gravity intervals for each instrument are sorted according to increasing size of the absolute interval value. Variances are computed from the residuals in groups of 100. The mean absolute interval size is determined for each variance. A least squares straight line fit is made to obtain the A and B terms of equation (1). The B term, slope, is tested for significance with a t-test. The probability of the t-value is computed.

The number of equations (variances), instrument number, A, B and the t-value are listed. If one minus the probability of the t-values (1 - P (t)) is greater than 0.05, a message "This is not significant" is listed. If (1 - P (t)) is less than 0.01 the message "This is very significant" is listed.

If there are less than 5 variances for the instrument, this test is by-passed. If the A or B term is negative, the test results are ignored.

2.4.3. Adjusted values, Table 5

The computation date, number of observations and unknowns, standard error of unit weight, datum code, rejection limit and adjustment number are listed followed by :

the unknown number, base number, letter and name, preliminary gravity value, correction, adjusted gravity value and standard error of the adjusted gravity value, for all bases included in the adjustment ;

the unknown number, agency and trip, instrument, scale correction factor and its standard error, for all scale factor unknowns ;

the unknown number, agency and trip, instrument drift correction factor, standard error of the drift correction factor, degrees of freedom, t-value and a significance message for the drift correction factor, for all drift unknowns.

2.4.4. Measurements, Table 6

The weight, IGB numbers and site letters, reading interval, time interval, agency and trip, instrument, base names, v and $v\sqrt{p}$ values are listed for measurements, followed by the number of rejected measurements.

2.4.5. Histograms, Table 7

Histograms are listed for each instrument and for all instruments combined. Class limits are selected so the expected frequency of occurance in each class is ten percent of the sample of $v\sqrt{p}$ values. The chi-squares value, its probability, the 1st through 4th moments of the distribution, values for relative skewness and relative kurtosis and significance messages for skewness and kurtosis are listed.

2.4.6. Dependency of residuals on elevation changes, Table 8

The relationship between residuals and elevation differences between bases is computed, with an equat. n of the form,

$$Y = BX \tag{4}$$

where Y is the residual, B is the slope of a regression line passing through the origin and X is the elevation difference. The slope is tested for significance with a t-test at the 0.05 and 0.01 levels. The instrument number, slope, standard error of the slope, degrees of freedom, t-value, $t_{.05}$ and $t_{.01}$ are listed with significance messages, as in 1.4.2.

The tests are made to investigate pressure sensitivity of the instruments.

2.4.7. Variance ratio tests on weights, Table 8

A variance is computed for each instrument with the equation :

$$VAR = \Sigma pvv / N \tag{5}$$

where N is the number of unrejected measurements for the instrument. A variance ratio test is made to see if the variance differs significantly from unity. The 0.05 test level is used.

The variance ratio, degrees of freedom, variance and weight correction factor are listed for each instrument. If the variance does not differ significantly from unity, a weight correction factor of 1.00 is listed. Since weights are determined as the reciprocal of the variance, a significant variance estimate determined from equation (5) can be multiplied by the A - term of the variance estimate discussed in 2.2.6 to obtain an updated variance estimate for the next adjustment. This method of updating the variarce estimates is used when the tests for dependency of variances on interval size, discussed in 2.4.2, show the B-term is insignificant or when the tests are inconclusive because of negative A or B - terms or when degrees of freedom are less than 3.

3. – ADJUSTMENTS

A revised data tape and list of corrections for LCR observations were received from OGST in Feb. 71. IGSSq data files were updated with the revised data and corrections. Preliminary adjustments were made to evaluate the data for the IGSN 71. The main adjustments are summarized in *Table 9*.

3.1. LaCoste–Romberg gravimeter measurements

LCR gravimeter measurements, centered to primary bases, were adjusted to resolve base designation and excenter value conflicts between OGST and GSS. Absolute measurements were used to define datum and scale. In the first edit all LCR gravimeter measurements were weighted based on a variance of 0.0036. Variance estimates were updated between adjustments based on variance ratio tests (2.4.6), or on the relationship between variances and size of the interval measured (2.2.6).

The final edit of LCR data is shown as adjustment 1 in *Table 9*. Rejections were made on absolute values of $v\sqrt{p}$ exceeding 4. Sixty-two gravimeter scale correction factors and 474 corrections to preliminary gravity values were obtained from the adjustment. No absolute measurements were rejected and 3.3 percent of the LCR observed gravity differences were rejected. The standard error of unit weight of 1.04 indicated that the assigned weights were approximately correct for the over all adjustment.

Variance ratio tests indicated that 11 of the gravimeters needed additional weight corrections. Tests for dependency of variances on interval size measured gave a t-value of 9.0

with 28 degrees of freedom for all LCR's taken as a group. The hypothesis of no relationship between variance and size of interval measured could not be sustained even at the 0.001 test level.

3.2. Pendulum and non-LCR gravimeter measurements

Gravity values determined in Adjustment 1 of *Table 9* were held fixed and all measurements, centered to primary bases, from tape file D of *Figure 1* were used in editing adjustments.

The adjustments solved for 70 corrections to preliminary gravity values and 50 scale correction factors for gravimeters and pendulums. t -tests indicated that scales of measurements from the Japanese, Italian (two trips of three) and Gulf K (early trips) differed significantly from the scale based on absolute measurements. Drift unknowns had not been included for the pendulum measurements so that fact could account for some of the differences. Fortunately, the great majority of pendulum measurements agreed satisfactorily in scale with the absolute measurements.

The final edit is shown as Adjustment 2 in *Table 9*. The high percentage of rejections (14.7) and deviation of the standard error of unit weight from unity (1.23) indicated that the weights had not normalized the $v\sqrt{p}$ values. The weights were corrected before Adjustment 3.

Test for dependency of variances on absolute size of the measured intervals showed insignificant t-values for individual pendulums and non-LCR gravimeters. In most cases the relationship may have been buried in instrument noise since the degrees of freedom were usually small for the test. When the pendulum and non-LCR gravimeter measurements were tested as a group, the t -value was 5.04 with 27 degrees of freedom. Although this is not a very good grouping, the large t -value may indicate that the gravimeters or pendulums, or both, have variances which are dependent on absolute size of the interval measured.

In preparation for Adjustment 3, variance estimates for the non-LCR and pendulum measurements were updated based on the variance ratio tests.

3.3. First combined adjustment

All pendulum, gravimeter and absolute measurements, corrected to primary bases, were combined for editing adjustments. Weights were updated based on the results of Adjustments 1 and 2 of *Table 9*. All scale factor unknowns were deleted from the pendulum measurements except for the three cases mentioned in 3.2 above. A rejection limit of 4 rejected all ties to several bases aborting the first adjustment. The rejection limit was changed to 10 for Adjustment 3 of *Table 9*.

Adjustment 3 solved for 541 corrections to preliminary gravity values and 101 scale factors. The 1.34 standard error of unit weight indicated that the weights were still out of balance. Removal of the scale unknowns had increased the variances for most of the pendulum surveys.

Corrections to preliminary gravity values were generally less than 0.2 mGal with the exception of a few bases that had been observed only with pendulum apparatus.

3.4. Second combined adjustment

Adjustment 4 of *Table 9* was run in the writer's absence and, unfortunately, the weights were not updated between Adjustments 3 and 4. The preliminary gravity values were updated on the control file after Adjustment 3 and the rejection limit was lowered to 4 for Adjustment 4.

Adjustment 4 solved for 541 corrections to preliminary gravity values and 101 scale factors. Corrections to preliminary gravity values were less than 0.2 mGal with the exception of two bases observed only by pendulum apparatus.

Three percent of the observed gravity differences were rejected. This is an acceptable level considering the number of opportunities for making gross errors in international gravity measurements. The percentage was slightly inflated because the weights for pendulum measurements were not corrected after Adjustment 3 of *Table 9*. As a result, most of the pendulum measurements had weights which were too large. The large weights, in turn, made the $v\sqrt{p}$ values too large so too many pendulum measurements were rejected.

4. – DISCUSSION OF RESULTS

4.1. Adjustment Comparisons

4.1.1. Introduction

Gravity values from Adjustments 1, 2 and 3 are compared with gravity values from Adjustment 4 (*Table 9*) in *Figures 2, 3* and *4*. The ordinates of the graphs are gravity differences between adjustments in mGal. The number of differences falling in each location is shown on each graph. When the number exceeded nine a + is shown.

4.1.2. Comparison between Adjustments 1 and 4

The slight downward trend with increasing gravity in *Figure 2* resulted from the scale contribution of the pendulum measurements. The addition of the pendulum measurements decreased the scale by 2×10^{-5}. The six differences greater than 0.10 mGal resulted from the addition of the Askania and other non-LCR gravimeter measurements in Africa.

4.1.3. Comparison between Adjustments 2 and 4

The difference greater than 0.40 mGal in *Figure 3* was at Umiat, Alaska. Umiat was tied to the network with a few USCGS pendulum measurements. The difference at Umiat was caused by use of a scale unknown with the pendulum measurements in Adjustment 2, and by retention of pendulum measurements in Adjustment 4 which were rejected in Adjustment 2. The difference of 0.20 was at Syowa, a base in Antarctica tied to the network only with the GSI pendulum apparatus. The Syowa difference was caused by the rejection of two pendulum measurements in Adjustment 4 which were retained in Adjustment 2.

4.1.4. Comparison between Adjustments 3 and 4

The differences between Adjustments 3 and 4, *Figure 4*, were caused by the very large (10 sigma) rejection limit used in Adjustment 3. Retention of measurements with gross errors of up to 5 mGal for pendulums and up to 0.7 mGal for gravimeters in Adjustment 3 resulted in the gravity base differences of up to 0.26 mGal and an apparent scale difference of 3×10^{-5} between Adjustments 3 and 4. The fact that the 10 sigma rejection limit resulted in only one difference outside of the range ± 0.16 mGal gives an indication of the strength of the net. Chiba, the base with the -0.26 difference, was tied to the network only with the GSI pendulum apparatus.

4.2. Absolute Measurements

Table 10 shows residuals and weights for absolute measurements from Adjustments 1, 3 and 4. Adjustment 2 residuals are not shown since they are the same as those shown for Adjustment 1. The residuals were obtained by subtracting the adjusted values from the observed values. The largest residuals occur at Bogota where intense microseismic noise was reported by the observers. The Bogota measurement received approximately one-fourth the weight assigned to the other Faller-Hammond measurements. The *Table 10* weight for Sakuma's Paris value was too high since it was based on precision instead of accuracy. The relative weight for Sakuma's Paris value was reduced for the final IGSN 71 adjustments made in Ottawa.

The remarkable thing about the residuals for the modern absolute measurements used in the adjustments is not how large they are, but how small they are. The three absolute apparatus give results which agree within 0.1 mGal, based on comparisons at Teddington and Paris. The

Table 10 residuals are no larger than could be expected when the weights are taken into consideration. The *Table 10* residuals do not indicate that serious non-linearities exist in the results of the gravimeter measurements.

5. – SUMMARY

Preliminary adjustments by the IGSSq show that the IGSN 71 data can provide an internally consistent network of gravity bases, covering a large portion of the earth, with gravity values on the absolute system. The modern absolute measurements define datum to a few hundreths of a mGal. Scale provided by relative measurements of gravity with pendulum apparatus is not significantly different from scale as determined by the absolute measurements. Good net strength was provided largely by measurements from groups of LaCoste-Romberg gravimeters. If the LaCoste-Romberg gravimeters give non-linear results they would distort the IGSN 71. Examination of adjustment residuals from the absolute measurements does not reveal significant non-linearities in the net.

Table 1 : Set Up Instructions, Base Net Program.

```
C          ***** SETUP INSTRUCTIONS FOR GRAVITY BASE NET PROGRAM *****
C                          EFFECTIVE 14 MAY 1971
C
C
C/////  CARD 1 - WILL CONTAIN THE PROJECT NAME, DATUM AND SCALE CODE ON WHICH
C                THE PROJECT IS TO BE COMPUTED, REJECTION LIMIT, ADJUSTMENT
C                NUMBER, CODE FOR INTERVAL AND V LISTING, CODE FOR TAPE, CODE
C                FOR ADJ., AND CODE FOR OBSERVATION INPUT BY CARDS.
C     COL 1-18 = PROJECT NAME,  COL 20-21 = DATUM AND SCALE CODE,  COL 23-27 =
C     REJECTION LIMIT,  COL 29-34 = ADJUSTMENT NUMBER OR THE WORD ALL.  IF THE
C     WORD ALL IS IN COLS 29-31 THE ADJUSTMENT WILL NOT BE DONE BY PRIMARIES,
C     COL 36 = CODE FOR INTERVAL AND V LISTING(IF LISTING IS NOT WANTED PLACE A
C     1 IN COL 36 OTHERWISE LEAVE BLANK),  COL 38 = CODE FOR TAPE(IF A TAPE IS
C     NOT WANTED PLACE A 1 IN COL 38 OTHERWISE LEAVE BLANK(TAPE WILL BE ON B1)),
C     COL 40 = CODE FOR ADJUSTMENT(IF ADJUSTMENT IS NOT TO BE EXECUTED PLACE A 1
C     IN COL 40 OTHERWISE LEAVE BLANK),  COL 42 = CODE FOR OBS. INPUT BY CARDS(
C     IF CARDS ARE TO BE USED INSTEAD OF BASE NET OBS. TAPE PLACE A 1 IN COLUMN
C     42 OTHERWISE LEAVE BLANK)
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890
BASE NET TEST      03  4.00 ALL    1 1 1 1
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
C
C/////  NEXT GROUP - THIS GROUP WILL BE INCLUDED ONLY IF THERE IS A 1 IN COL 42
C                    OTHERWISE IGNORE THIS GROUP.  IF THIS GROUP IS USED(A 1 IN
C                    COL 42) INSTRUMENT DATA MUST HAVE, A HEADER CARD, OBSERVA-
C                    TION CARDS, AND A BLANK CARD TO END THE INSTRUMENT DATA.
C                    THERE MUST BE 2 BLANK CARDS FOLLOWING THE LAST SET OF DATA.
C**********     LIMIT IS 120 CARDS PER INSTRUMENT                     **********
C
C
C/////  NEXT GROUP - WILL CONTAIN THE IGB'S THAT ARE NOT TO BE USED IN THE ADJ.
C       COL 1-6 = IGB
C**********     LIMIT IS 160 IGB CARDS                                **********
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890
15514X
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
C----------  A BLANK CARD WILL END THIS GROUP OF IGB'S.  ----------------------
C
C
C/////  NEXT GROUP - WILL CONTAIN THE IGB'S THAT ARE TO BE EQUIVALENCED.
C       COL 1-6 = OLD IGB NUMBER,  COL 9-14 = REPLACING IGB NUMBER.
C**********     LIMIT IS 50 EQUIVALENCE CARDS                         **********
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777778
1234567890123456789012345678901234567890123456789012345678901234567890
 1436A   1437A
C++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
C---------- A BLANK CARD WILL END THE EQUIVALENCES. ---------------------------
```

Table 1 (suite).

```
C
C/////  NEXT GROUP - WILL CONTAIN THE FIXED IGB'S.  IF THE GRAVITY VALUE ON THE
C                    CONTROL CARD TAPE IS NOT CORRECT YOU CAN ENTER THE VALUE
C                    THAT YOU WANT ON THE CARD ALSO PLACE THE DATUM CODE OF THE
C                    VALUE THAT YOU ENTERED ON THE CARD.
C     COL 1-6 = IGB,  COL 8-17 = BASE GRAVITY VALUE,  COL 19-20 = DATUM CODE
C     THAT THE GRAVITY VALUE IS ON.
C**********     LIMIT IS 500 FIXED IGB CARDS                        **********
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
 1436A 980761.930 02
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
C---------- A BLANK CARD WILL END THE FIXED STATIONS. -------------------------
C
C
C/////  NEXT GROUP - WILL CONTAIN AGENCY AND TRIP NUMBER, INST. NUMBER, DRIFT
C                    CODE, SCALE CODE, AGENCY AND TRIP AND INST. NUMBER FOR
C                    DRIFT, AGENCY AND TRIP AND INST. NUMBER FOR SCALE, DRIFT
C                    CORRECTION FACTOR, SCALE CORRECTION FACTOR(DFSCF), AND THE
C                    WEIGHT A AND B VALUES.
C     COL 1-4 = AGENCY AND TRIP NUMBER,  COL 5-8 = INST. NUMBER,  COL 10-14 =
C     CODE DRIFT(IF DRIFT IS TO BE SOLVED FOR OTHERWISE LEAVE COL 10-14 BLANK),
C     COL 16-20 = CODE SCALE(IF SCALE IS TO BE SOLVED FOR OTHERWISE LEAVE
C     COL 16-20 BLANK),  COL 22-29 = AGENCY AND TRIP AND INST. NUMBER FOR DRIFT
C     EQUIVALENCE(LEAVE BLANK IF NO EQUIVALENCE),  COL 31-38 = AGENCY AND TRIP
C     AND INST. NUMBER FOR SCALE EQUIVALENCE(LEAVE BLANK IF NO EQUIVALENCES),
C     COL 39-47 = BLANK,                COL 48-56 = DRIFT CORRECTION FACTOR
C     COL 57-65 = SCALE CORRECTION FACTOR(DFSCF),  COL 66-72 = WEIGHT A VALUE,
C     COL 73-79 = WEIGHT B VALUE MULTIPLIED BY 1000.
C**********     LIMIT IS 400 INSTRUMENT CARDS                       **********
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
0204L043 DRIFT SCALE 0204L044 0204L045                    .998531  .001  .C012
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
C---------- A BLANK CARD WILL END THIS GROUP.  ALSO THE AGENCY AND TRIP --------
C---------- AND INST. NUMBERS IN COL 1-8 WILL BE USED TO PULL THE -------------
C---------- OBSERVATIONS OFF OF THE MASTER TAPE. ------------------------------
C
C
C
C/////  NEXT GROUP - WILL CONTAIN THE ADDITIONAL TIES FOR THE PROJECT.
C     COL 1-4 = WEIGHT,  COL 6-11 = IGB1,  COL 13-18 = IGB2,  COL 19-27 =
C     READING INTERVAL,  COL 28-33 = TIME INTERVAL,  COL 35-38 = AGENCY AND TRIP
C     CODE,  COL 39-42 = INST. NUMBER,  COL 45 = TABLE NUMBER,  COL 47-54 =
C     DFSCF,  COL 56-67 = BASE NAME 1,  COL 69-80 = BASE NAME 2.
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
         1111111111222222222233333333334444444444555555555566666666667777777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C1.0 19476B 19476N  -32.473 34.31 0204L044  2 1.000321 CHEYENNE B   CHEYENNE N
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++C
C
```

Table 2 : Gravimeter Data Output for Editing Purposes

1ST GEODETIC SURVEY SQUADRON,F.E.WARREN AFB,WYOMING 82001
COMPUTATIONAL DATE 16 FEB 1971

INTERVAL LISTING FOR PROJECT STATE BASE NETS
INSTRUMENT = LC4200 AGENCY AND TRIP = C467 DFSCF = 0.998624 DATUM CODE = 3

IGB	BASE STATION NAME	YR	GCD	GCT	READING	DH	P.C.	CEC	E.T.	C. RDG.	T.INT.	R.INT.	BGV	V
08161R	LEESBURG R FL	64	57	1935	2707.83	-0.00	0.00	-0.01	0.01	2626.68	2.67	-51.74	979230.16	0.05
08161K	ORLANDO K FL	64	57	2056	2586.43	-0.00	0.00	0.00	-0.05	2804.28	1.35	-22.40	979207.74	-0.02
08161K	ORLANDO K FL	64	59	1322	2686.52	-0.00	0.00	-0.00	-0.08	2804.34	40.43	0.05	979207.74	-0.05
08160N	INDIAN RIVER N FL	64	59	1536	2698.81	-0.00	0.00	-0.01	0.01	2817.26	2.23	12.92	979220.69	0.03
08160L	MERRITT ISLAND L F	64	59	1736	2682.72	-0.00	0.00	-0.01	0.08	2800.53	2.00	-16.73	979204.03	0.07
08160J	COCOA J FL	64	59	1842	2672.34	-0.00	0.00	0.01	0.09	2789.71	1.10	-10.82	979193.18	-0.02
08160L	MERRITT ISLAND L F	64	59	1930	2682.77	-0.00	0.00	-0.01	0.07	2800.57	0.80	10.86	979204.03	-0.02
08160N	INDIAN RIVER N FL	64	59	2025	2698.80	-0.00	0.00	-0.01	0.04	2817.28	0.92	16.71	979220.69	-0.05
08161K	ORLANDO K FL	64	59	2137	2586.42	-0.00	0.00	0.00	-0.01	2804.31	1.20	-12.97	979207.74	0.02
08161K	ORLANDO K FL	64	62	13 3	2686.52	-0.00	0.00	-0.00	-0.07	2804.35	63.42	0.04	979207.74	-0.04
08161S	SANFORD S FL	64	62	1358	2716.43	-0.00	0.00	0.00	-0.07	2835.60	0.92	31.25	979238.96	-0.03
08190J	NEW SMYRNA BCH J F	64	62	1532	2736.23	-0.00	0.00	0.01	-0.03	2856.32	1.57	20.73	979259.71	0.03
08160N	INDIAN RIVER N FL	64	62	17 0	2698.60	-0.00	0.00	-0.01	0.02	2817.26	1.47	-39.06	979220.69	0.04
08161K	ORLANDO K FL	64	62	1844	2686.39	-0.00	0.00	0.01	0.08	2804.37	1.73	-12.89	979207.74	-0.05
08161K	ORLANDO K FL	64	64	1255	2586.58	-0.00	0.00	-0.00	-0.04	2804.44	42.18	0.07	979207.74	-0.07
08161Q	KISSIMMEE Q FL	64	64	1528	2644.41	-0.00	0.00	0.00	-0.04	2760.40	2.55	-44.04	979163.72	0.03
08161V	HOLOPAW V FL	64	64	1650	2536.72	-0.00	0.00	-0.01	-0.01	2752.38	1.37	-8.02	979155.69	-0.02
08160M	MELBOURNE M FL	64	64	18 3	2653.97	-0.00	0.00	-0.00	0.02	2770.44	1.22	18.06	979173.78	0.03
08160K	COCOA K FL	64	64	19 6	2681.08	-0.00	0.00	0.00	0.05	2798.79	1.05	28.35	979202.14	0.01
08160N	INDIAN RIVER N FL	64	64	1943	2698.85	-0.00	0.00	-0.01	0.06	2817.36	0.62	18.56	979220.69	-0.01
08161K	ORLANDO K FL	64	64	2117	2586.42	-0.00	0.00	0.00	0.08	2804.40	1.57	-12.96	979207.74	0.00
08161K	ORLANDO K FL	64	65	13 4	2686.58	-0.00	0.00	-0.00	-0.03	2804.45	15.78	0.05	979207.74	-0.05
08161S	SANFORD S FL	64	65	14 2	2716.48	-0.00	0.00	0.00	-0.04	2835.68	0.97	31.23	979238.96	-0.01
08191R	DELAND R FL	64	65	1517	2731.45	-0.00	0.00	0.00	-0.04	2851.32	1.25	15.64	979254.61	0.01
08191H	PIERSON H FL	64	65	1627	2727.23	-0.00	0.00	0.01	-0.03	2846.93	1.17	-4.39	979250.23	0.01
08162L	UMATILLA L FL	64	65	1735	2711.06	-0.00	0.00	0.00	-0.01	2830.05	1.13	-16.88	979233.35	-0.00
08161T	HOWEY T FL	64	65	1844	2697.90	-0.00	0.00	-0.00	0.02	2816.32	1.15	-13.73	979219.64	0.02
08161K	ORLANDO K FL	64	65	2038	2586.47	-0.00	0.00	0.00	0.06	2804.43	1.90	-11.89	979207.74	-0.00
08161Q	KISSIMMEE Q FL	64	69	1650	2644.40	-0.00	0.00	0.00	0.00	2760.43	92.20	-43.99	979163.72	-0.02
08161P	WINTER HAVEN P FL	64	69	1827	2636.25	-0.00	0.00	0.01	-0.02	2751.90	1.62	-8.54	979155.19	0.01
08162L	LAKELAND L FL	64	69	1953	2653.14	-0.00	0.00	0.01	-0.04	2769.49	1.43	17.60	979172.75	-0.04
08161Q	KISSIMMEE Q FL	64	69	2121	2644.44	-0.00	0.00	0.00	-0.04	2760.43	1.47	-9.07	979163.72	0.04
08161S	SANFORD S FL	64	70	1349	2716.49	-0.00	0.00	0.00	-0.00	2635.72	16.47	75.30	979238.96	-0.06
08191T	SAMSULA T FL	64	70	15 0	2732.53	-0.00	0.00	-0.00	0.02	2852.51	1.18	16.78	979255.80	0.06
08190J	NEW SMYRNA BCH J F	64	70	1532	2736.38	-0.00	0.00	0.01	0.03	2856.54	0.53	4.04	979259.71	-0.12
08191J	DAYTONA BEACH J FL	64	70	1612	2739.03	-0.00	0.00	0.00	0.03	2859.31	0.67	2.77	979262.51	0.03
08191S	BUNNELL S FL	64	70	17 6	2760.02	-0.00	0.00	0.00	0.02	2881.22	0.90	21.92	979284.42	-0.00
08191H	PIERSON H FL	64	70	1836	2727.31	-0.00	0.00	0.01	-0.02	2847.02	1.50	-34.20	979250.23	0.01
08191R	DELAND R FL	64	70	1917	2731.54	-0.00	0.00	-0.00	-0.04	2851.41	0.68	4.39	979254.61	-0.01
08161S	SANFORD S FL	64	70	20 9	2716.60	-0.00	0.00	-0.00	-0.05	2835.78	0.87	-15.63	979238.96	-0.02
08161Q	KISSIMMEE Q FL	64	71	14 3	2644.52	-0.00	0.00	-0.00	-0.00	2760.55	17.90	-75.24	979163.72	0.00
08161V	HOLOPAW V FL	64	71	1521	2636.80	-0.00	0.00	-0.01	0.04	2752.52	1.30	-8.03	979155.69	-0.00
08170P	YEEHAW JUNCTION P	64	71	1617	2649.60	-0.00	0.00	-0.00	0.05	2765.91	0.93	13.39	979169.07	-0.01
08171J	LAKE WALES J FL	64	71	1812	2636.47	-0.00	0.00	0.00	0.03	2752.17	1.92	-13.74	979155.36	0.03
08161Q	KISSIMMEE Q FL	64	71	1921	2644.53	-0.00	0.00	-0.00	-0.02	2760.54	1.15	8.37	979163.72	-0.01

Table 3 : Rejected Measurements

1.000	46738A	57399A	2893.800		1.000	JP04	2A1	1.00000000	CAPETOWN	SYOWA BASE	
488	-1.00	506	1.00	0	-0.04	542	-2.89	0	0.00	-1.67	0.00
1.000	13159A	06230A	-1485.105		1.000	JP05	2A1	1.00000000	TOKYO	BANGKOK	
174	-1.00	66	1.00	0	-0.04	542	1.49	0	0.00	-2.05	0.00
1.000	06230A	13159A	1494.557		1.000	JP05	2A2	1.00000000	BANGKOK	TOKYO	
66	-1.00	174	1.00	0	-0.04	542	-1.49	0	0.00	-7.42	0.00
1.000	46738A	57399A	2889.795		1.000	JP04	2D0	1.00000000	CAPETOWN	SYOWA BASE	
488	-1.00	506	1.00	0	-0.04	542	-2.89	0	0.00	2.34	0.00
1.000	57399A	46738A	-2889.167		1.000	JP04	2D0	1.00000000	SYOWA BASE	CAPETOWN	
506	-1.00	488	1.00	0	-0.04	542	2.89	0	0.00	-2.97	0.00
1.000	13159A	06230A	-1453.951		1.000	JP05	2D0	1.00000000	TOKYO	BANGKOK	
174	-1.00	66	1.00	0	-0.04	542	1.45	0	0.00	-33.20	0.00
1.000	06230A	13159A	1483.837		1.000	JP05	2D0	1.00000000	BANGKOK	TOKYO	
66	-1.00	174	1.00	0	-0.04	542	-1.48	0	0.00	3.31	0.00
1.000	23147A	13159A	-2441.971		1.000	JP07	3D0	1.00000000	FAIRBANKS	TOKYO	
347	-1.00	174	1.00	0	-0.04	542	2.44	0	0.00	-2.55	0.00
1.000	06050A	02613A	-313.200		1.000	JP08	3D0	1.00000000	MANILA	SINGAPORE	
63	-1.00	18	1.00	0	-0.04	542	0.31	0	0.00	-2.45	0.00
1.000	13159A	45331A	-124.437		1.000	JP09	3D0	1.00000000	TOKYO	SYDNEY	
174	-1.00	480	1.00	0	-0.04	542	0.12	0	0.00	9.06	0.00
1.000	45331A	95459A	-62.070		1.000	JP09	3D0	1.00000000	SYDNEY	CANBERRA	
480	-1.00	525	1.00	0	-0.04	542	0.06	0	0.00	-6.21	0.00
1.000	45331A	95459A	-73.653		1.000	JP09	3D2	1.00000000	SYDNEY	CANBERRA	
480	-1.00	525	1.00	0	-0.04	542	0.07	0	0.00	5.37	0.00

Table 4 : Dependency of Variances on Interval Size

```
DEPENDENCY OF VARIANCES ON INTERVAL SIZE

              10 EQUATIONS
STANDARD ERROR =     0.007825 FOR L001  000000
  INTERCEPT=       0.002591 SLOPE=   0.00000677
 T VALUE=    1.776918  K VALUE=     1.591716
 THIS IS NOT  SIGNIFICANT


              13 EQUATIONS
STANDARD ERROR =     0.065286 FOR L002  000000
  INTERCEPT=       0.001672 SLOPE=   0.00003224
 T VALUE=    3.356426  K VALUE=     2.924415
 THIS IS VERY SIGNIFICANT


              13 EQUATIONS
STANDARD ERROR =     0.006096 FOR L004  000000
  INTERCEPT=       0.001316 SLOPE=   0.00000630
 T VALUE=    3.754807  K VALUE=     3.339041
 THIS IS VERY SIGNIFICANT


              21 EQUATIONS
STANDARD ERROR =     0.049870 FOR L005  000000
  INTERCEPT=       0.002777 SLOPE=   0.00002677
 T VALUE=    3.921500  K VALUE=     3.438546
 THIS IS VERY SIGNIFICANT


              18 EQUATIONS
STANDARD ERROR =     0.193515 FOR L007  000000
  INTERCEPT=      -0.010375 SLOPE=   0.00008316
 T VALUE=    3.377019  K VALUE=     2.967773
 THIS IS VERY SIGNIFICANT


              21 EQUATIONS
STANDARD ERROR =     0.058626 FOR L009  000000
  INTERCEPT=       0.003719 SLOPE=   0.00002330
 T VALUE=    3.835414  K VALUE=     3.367263
 THIS IS VERY SIGNIFICANT
```

Table 5 : Adjusted Gravity Values

Note : Gravity values are for an example only – do not use.

1ST GEODETIC SURVEY SQUADRON,F.E.WARREN AFB,WYOMING 82001
COMPUTATIONAL DATE 14 MAY 1971
1178 OBSERVATIONS AND 642 UNKNOWNS

STANDARD ERROR OF UNIT WEIGHT = 1.0454
DATUM CODE 3 REJECTION LIMIT 4.00 ADJUSTMENT 1

UNK NR	IGB	STATION NAME	GRAVITY	CORR	ADJ. GRAVITY	SIGMA
401	35781J	ABERCORN J	977656.54	0.02	977656.56	0.000
2	00154J	ABIDJAN J	978060.84	0.02	978060.85	0.000
512	90154A	ABIDJAN A	978088.28	0.01	978088.29	0.000
57	C4669J	ACAPULCO J	978501.77	0.01	978501.78	0.000
1	00150A	ACCRA A	978091.36	0.01	978091.37	0.000
302	19816J	ADAK J AK	981427.77	-0.03	981427.74	0.000
23	03398J	ADDIS ABABA J	977431.09	0.03	977431.12	0.000
72	C6824J	ADEN J	978304.26	0.00	978304.26	0.000
120	10909J	AGADIR J	979319.64	0.01	979319.65	0.000
271	18040J	AGEN J	980519.41	0.00	980519.41	0.000
112	10177J	AGRA J	979039.84	-0.06	979039.78	0.000
109	10132J	AHMEDABAD J	978813.95	-0.10	978813.85	0.000
152	11926J	ALAMAGORDO J NM	979116.30	0.01	979116.31	0.000
136	11714J	ALBANY J GA	979438.58	0.01	979438.59	0.000
155	11956B	ALBUQUERQUE B NM	979210.63	0.01	979210.63	0.000
482	45466J	ALBURY J	979757.62	-0.01	979757.61	0.000
380	29522J	ALERT	983129.88	-0.02	983129.86	0.000
191	14463A	ALGIERS A	979896.86	0.01	979896.87	0.000
455	41933J	ALICE SPRINGS J	978639.30	-0.01	978639.29	0.000
354	25093J	ALTA J	982529.82	-0.02	982529.81	0.000
154	11951A	AMARILLO A TX	979409.12	0.00	979409.12	0.000
177	13714J	AMRITSAR J	979335.13	-0.06	979335.07	0.000
327	21625A	AMSTERDAM A	981254.35	-0.00	981254.35	0.000
344	23119A	ANCHORAGE A	981925.23	-0.02	981925.21	0.000
182	14192B	ANKARA B	979925.17	-0.00	979925.17	0.000
45	04371B	ANTIGUA B	978638.87	0.03	978638.90	0.000
448	40430A	ANTOFAGASTA A	978889.44	-0.00	978889.44	0.000
119	10871J	AOULEF J	978971.11	0.01	978971.11	0.000
317	21572J	APELVIKSAAS J	981701.95	-0.01	981701.94	0.000
417	36861K	AREQUIPA K	977701.64	0.02	977701.66	0.000
418	36880K	ARICA K	978479.98	0.01	978479.98	0.000
381	32674B	ASCENSION ISL	978289.35	0.01	978289.36	0.000
75	06958A	ASMARA A	977805.35	0.04	977805.38	0.000
441	40257B	ASUNCION B	978949.21	-0.00	978949.21	0.000
116	10542J	ASWAN J	978854.12	0.04	978854.16	0.000
183	14273A	ATHENS A	980031.08	-0.01	980031.07	0.000
521	94273M	ATHENS M	980043.64	0.00	980043.64	0.000
139	11734A	ATLANTA A GA	979523.57	0.01	979523.58	0.000
477	45164B	AUKLAND	979934.06	-0.01	979934.05	0.000
144	11807B	AUSTIN B TX	979270.29	0.00	979270.29	0.000
127	11187A	AZORES A	980110.75	0.01	980110.75	0.000
305	21510A	BAD HARZBURG A	981165.51	-0.00	981165.50	0.000
324	21609J	BAD HERSFELD J	981104.52	-0.00	981104.52	0.000
206	18030A	BAGNERES A	980272.25	0.01	980272.26	0.000
474	43982K	BAHIA BLANCA K	980052.75	-0.02	980052.73	0.000

Table 6 : Gravity Measurements and Residuals

WEIGHT	IGB	IGB	READING INTERVAL	TIME INTERVAL	AGENCY TRIP	INST	STATION NAME	STATION NAME	V	V(RT P)
100.		00844A	-2610.060	1.00	0805	11AB	FALLER	BOGOTA A	-0.158	-1.682
123.		11687A	104.250	1.00	0805	11AB	FALLER	WASHINGTON A	0.038	0.425
400.		11994A	-402.272	1.00	0805	11AB	FALLER	DENVER A	0.039	0.771
400.		15212A	305.322	1.00	0805	11AB	FALLER	MIDDLETOWN A	0.023	0.457
400.		15221A	378.692	1.00	0805	11AB	FALLER	BOSTON A	0.012	0.238
400.		15221A	378.704	1.00	0805	11AB	FALLER	BOSTON A	-0.000	-0.002
400.		18082A	925.991	1.00	0805	11AB	FALLER	PARIS A	-0.030	-0.598
278.		18110A	1181.696	1.00	0805	11AB	FALLER	TEDDINGTON A	-0.124	-2.074
278.		23147A	2231.728	1.00	0805	11AB	FALLER	FAIRBANKS A	-0.012	-0.198
59.		18110A	1181.840	1.00	0805	11AB	COOK	TEDDINGTON A	-0.068	-0.525
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
826.		18082A	925.957	1.00	0805	11AB	SAKUMA	PARIS A	0.004	0.118
1.	13050A	11687A	329.888	1.00	JP01	1A2	CHIBA	WASHINGTON	-0.677	-0.677
1.	11687A	13050A	-330.245	1.00	JP01	1A2	WASHINGTON	CHIBA	-1.034	-1.034
1.	13050A	02613A	-1709.609	1.00	JP02	1A2	CHIBA	SINGAPORE	-0.749	-0.749
1.	02613A	46738A	1565.167	1.00	JP02	1A2	SINGAPORE	CAPETOWN	1.206	1.206
1.	46738A	02613A	-1566.574	1.00	JP02	1A2	CAPETOWN	SINGAPORE	-0.201	-0.201
1.	02613A	13050A	1709.958	1.00	JP02	1A2	SINGAPORE	CHIBA	-1.098	-1.098
2.	13050A	11687A	329.541	1.00	JP01	1A3	CHIBA	WASHINGTON	-0.330	-0.452
2.	11687A	13050A	-328.587	1.00	JP01	1A3	WASHINGTON	CHIBA	0.624	0.854
2.	13050A	02613A	-1707.723	1.00	JP02	1A3	CHIBA	SINGAPORE	1.137	1.556
2.	46738A	02613A	-1566.324	1.00	JP02	1A3	CAPETOWN	SINGAPORE	0.049	0.067
2.	02613A	13050A	1709.630	1.00	JP02	1A3	SINGAPORE	CHIBA	-0.770	-1.054
2.	02613A	46738A	1565.688	1.00	JP02	1A3	SINGAPORE	CAPETOWN	0.685	0.938
6.	13159A	46738A	-154.723	1.00	JP04	2A1	TOKYO	CAPETOWN	-0.177	-0.442
0.	46738A	57399A	2893.800	1.00	JP04	2A1	CAPETOWN	SYOWA BASE	-1.062	-0.000
6.	57399A	46738A	-2892.798	1.00	JP04	2A1	SYOWA BASE	CAPETOWN	-0.060	-0.150

Table 7 : Histogram and Distribution Statistics

CLASS CENTERS FROM	TO	OBSERVED FREQUENCY	COMPUTED FREQUENCY	
1.282	INFNTY	24	25.0	•••••••••
.842	1.282	29	25.0	••••••••••
.524	.842	30	25.0	•••••••••••
.253	.524	22	25.0	••••••••
.000	.253	23	25.0	•••••••
-.253	.000	25	25.0	••••••••
-.524	-.253	30	25.0	•••••••••••
-.842	-.524	23	25.0	•••••••
-1.282	-.842	21	25.0	•••••••
INFNTY	-1.282	23	25.0	•••••••

REJECTION LIMIT = 4.000 SIGMA POPULATION = 1.04543 CHI-SQUARE VALUE = 4.160
PROBABILITY THAT THE DISTRIBUTION IS NORMAL IS 0.762734279
1ST MOMENT VALUE = 0.052037 2ND. MOMENT VALUE = 1.030917 3RD MOMENT VALUE = 0.041659
4TH MOMENT VALUE = 3.389074 RELATIVE SKEWNES = 0.002 RELATIVE KURTOSI = 3.189
SKEW NOT SIGNIFICANT
KURTOSIS NOT SIGNIFICANT
HISTOGRAM FOR INSTRUMENT L005

Table 8 : Correlation and Variance Ratio Test

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
11AB	0.0000	0.0000	19.	0.000	2.093	2.861	NOT SIGNIFICANT

VARIANCE RATIO 0.4727 DF= 19. VARIANCE 0.4727 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
1A2	-22.9069	23.3328	5.	-0.982	2.571	4.032	NOT SIGNIFICANT

VARIANCE RATIO 0.9576 DF= 5. VARIANCE 0.9576 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
1A3	-45.1514	17.8361	5.	-2.531	2.571	4.032	NOT SIGNIFICANT

VARIANCE RATIO 1.0704 DF= 5. VARIANCE 1.0704 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
2A1	-11.2478	19.5152	3.	-0.576	3.182	5.841	NOT SIGNIFICANT

VARIANCE RATIO 1.0667 DF= 3. VARIANCE 1.0667 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
2A2	6.6506	11.4654	6.	0.580	2.447	3.707	NOT SIGNIFICANT

VARIANCE RATIO 0.6323 DF= 6. VARIANCE 0.6323 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
2A3	52.6520	4.3847	1.	12.008	12.706	63.657	NOT SIGNIFICANT

VARIANCE RATIO 1.5589 DF= 1. VARIANCE 1.5589 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
2D0	31.5343	20.7573	1.	1.519	12.706	63.657	NOT SIGNIFICANT

VARIANCE RATIO 1.1875 DF= 1. VARIANCE 1.1875 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
2D2	-12.1196	17.4407	3.	-0.695	3.182	5.841	NOT SIGNIFICANT

VARIANCE RATIO 1.3357 DF= 3. VARIANCE 1.3357 WCF= 1.00

CORRELATION OF RESIDUALS WITH ELEVATION CHANGES

INST	M	SM	D.F.	T VALUE	.05 LVL	.01 LVL	
3A1	0.6032	0.4829	14.	1.249	2.145	2.977	NOT SIGNIFICANT

VARIANCE RATIO 1.3554 DF= 14. VARIANCE 1.3554 WCF= 1.00

Table 9

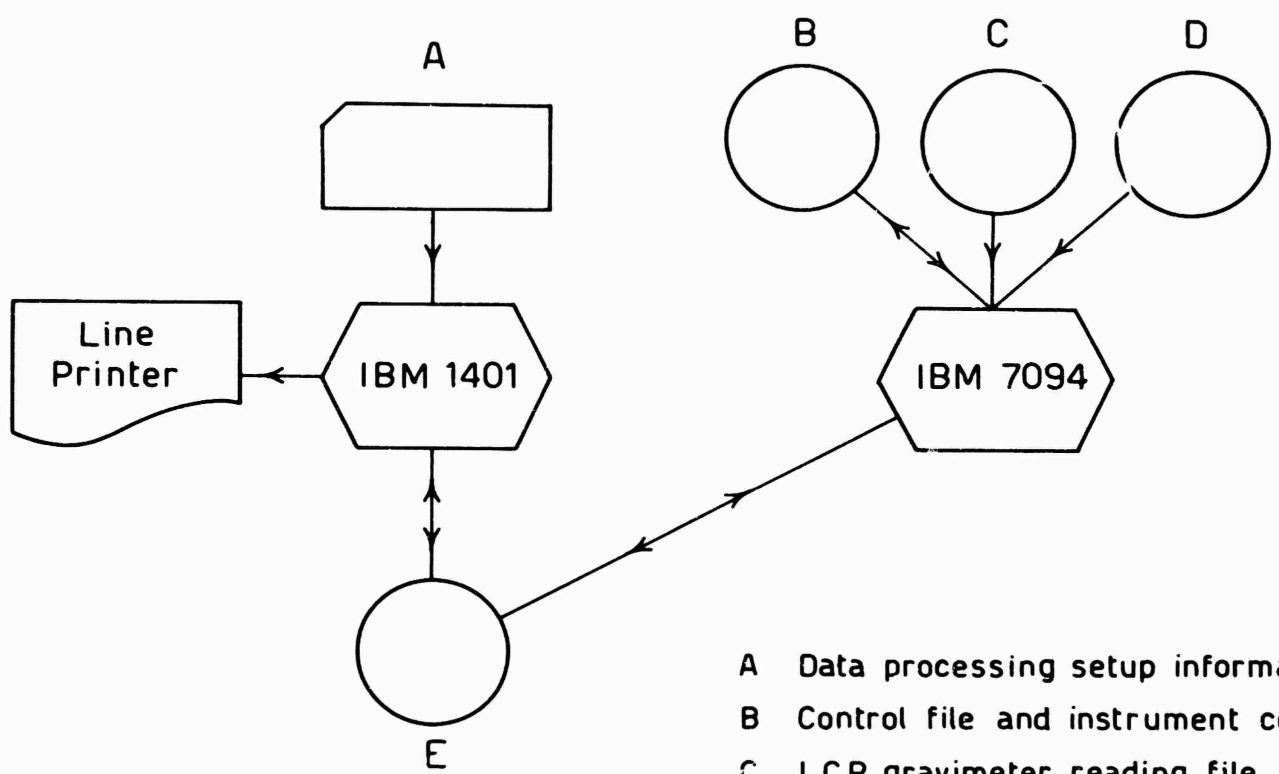
Summary of Adjustments

Adj.	Datum	Scale	Rejection Limit	Instruments			No. Obs.	No. Unk.	% Rej.	σ_o
				Gm.	Pend.	Abs.				
no. 1	Abs.	Abs.	4	X		X	8755	536	3.3	1.04
no. 2	Abs.	Abs.	4	X	X		1823	120	14.7	1.23
no. 3	Abs.	Abs. + Pend.	10	X	X	X	11041	642	1.2	1.34
no. 4	Abs.	Abs. + Pend.	4	X	X	X	10340	642	3.0	1.05

Table 10

Residuals for Absolute Gravity Measurements

Apparatus	Station	Adj. 1	Adj. 3	Adj. 4	Weight
Faller-Hammond	Bogota	-.093	-.240	-.168	100
Faller-Hammond	Washington	-.024	-.044	-.038	123
Faller-Hammond	Denver	.065	.028	.039	400
Faller-Hammond	Middletown	-.013	-.019	-.023	400
Faller-Hammond	Boston	-.004	-.002	-.012	400
Faller-Hammond	Boston	.008	.010	.000	400
Faller-Hammond	Paris	.028	.029	.030	400
Faller-Hammond	Teddington	.107	.123	.124	278
Faller-Hammond	Fairbanks	-.020	.048	.012	278
Cook	Teddington	.051	.067	.068	59
Sakuma	Paris	-.006	-.005	-.004	8260



A Data processing setup information

B Control file and instrument constants

C LCR gravimeter reading file

D Non-LCR Δg file

E 7094 input or output tape

Fig. 1 : Gravity Base Net Computer Work Flow

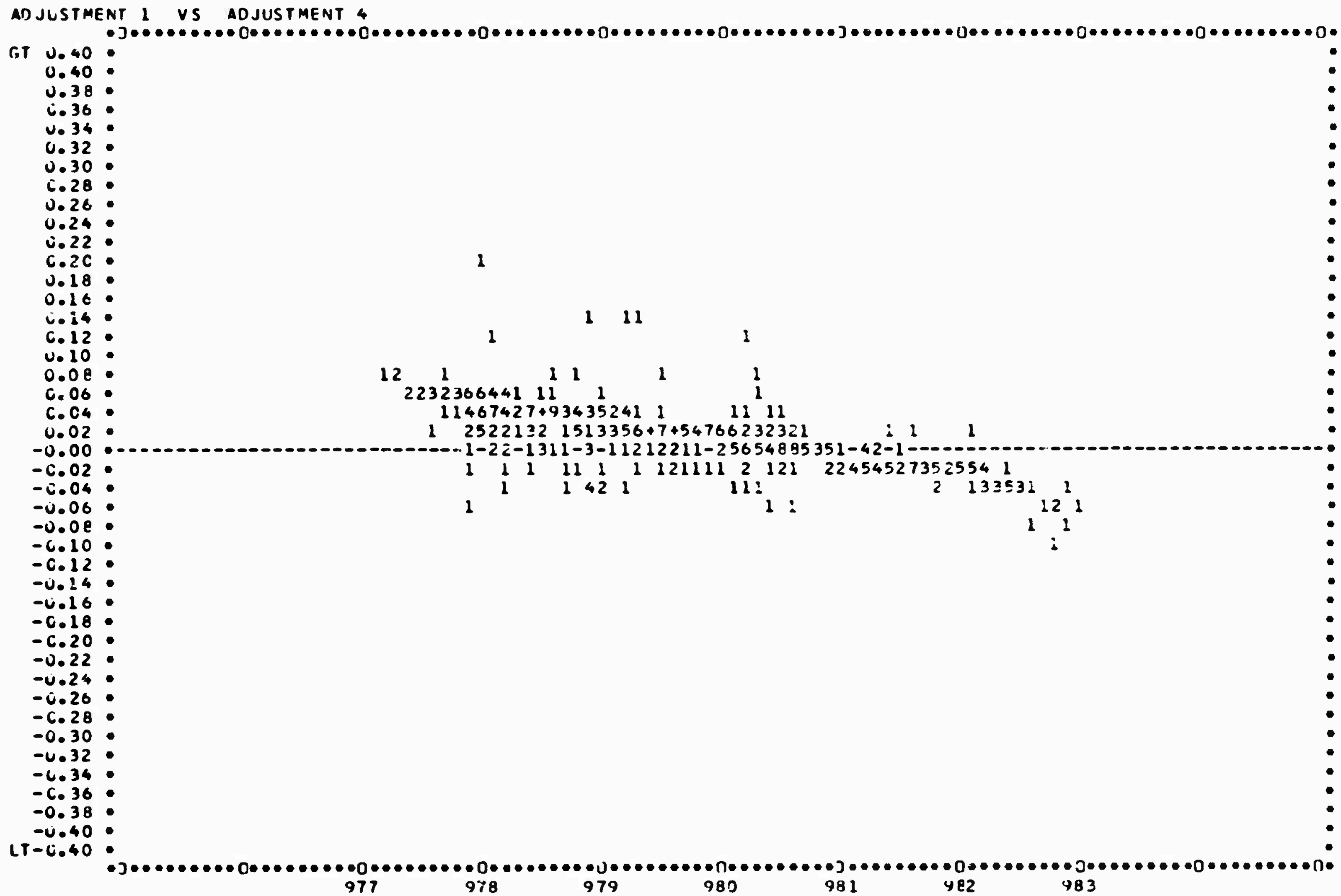


Fig. 2 : Comparison between Adjustments 1 and 4

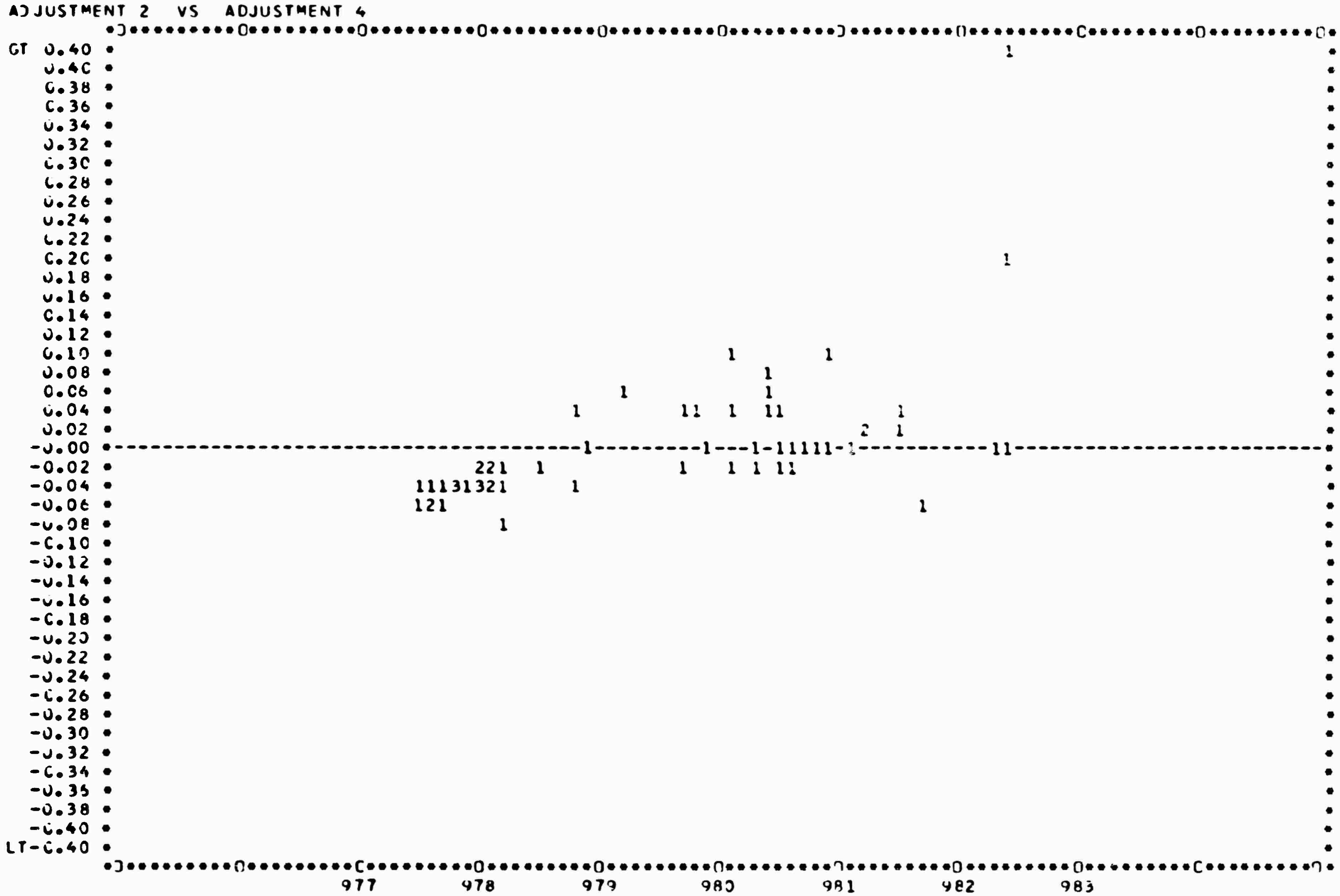


Fig. 3 : Comparison between Adjustments 2 and 4

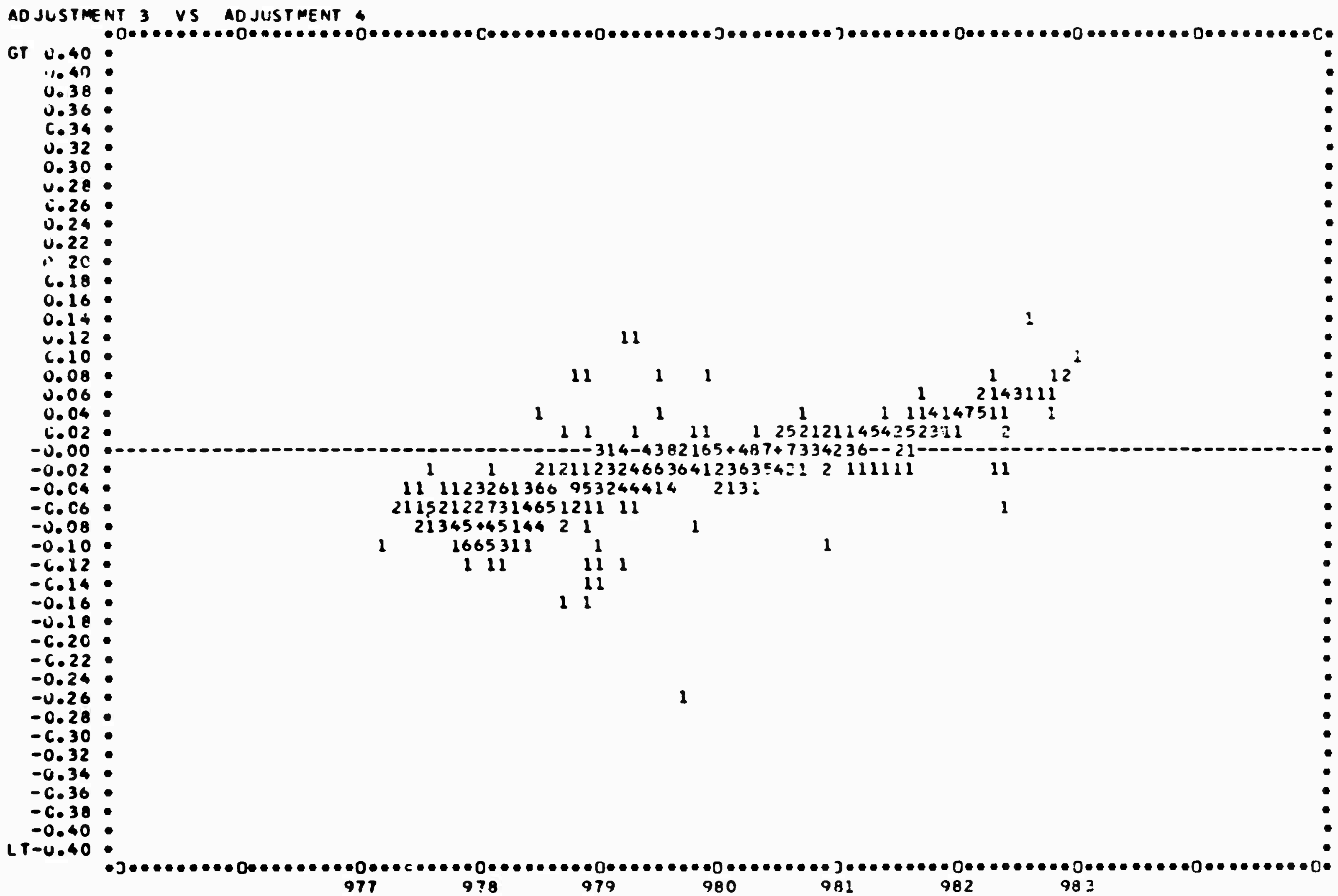


Fig. 4 : Comparison between Adjustments 3 and 4

APPENDIX IV

ADJUSTMENTS AND ANALYSES OF DATA FOR IGSN 71

Performed at Earth Physics Branch
Ottawa, Canada.

by

R.K. McConnell
Department of Energy,
Mines and Resources,
Ottawa, Canada.

and

C. Gantar
Osservatorio Geofisico
Sperimentale
Trieste, Italy.

Preceding page blank

TABLE OF CONTENTS

o

o o

1. – ADJUSTMENT CONCEPTS

1.1. Types of Errors in Gravity Networks

The errors in gravimeter and pendulum measurements may be classified into two categories : those occurring at the station and those occurring in transit between stations. Both types are assumed to have random and systematic components.

Errors which occur at the station are related to the observing procedures, the response of the instrument to the environment and to inaccuracies in determining corrections used in data reduction. The most common errors in observing procedure arise from site misidentification and improper recording of data. Errors induced by the environment include atmospheric pressure effects, magnetic effects, microseismic effects, mechanical vibrations, changes in the level of the water table and long term effects related to crustal movements. Station errors which arise from the reduction model include, for gravimeters, corrections for dial non-linearity, periodic screw errors, scale factor and earth tides. For pendulums the reduction procedure includes corrections for such quantities as temperature, humidity, pressure and sway.

Errors which occur between stations are related to environmental effects during transportation, to the length of time to which they are subjected to these effects and to changes in the mechanical behaviour or properties of the instrument. Changes that may be expressed as continuous functions of the elapsed time are generally referred to as *drift*; abrupt changes are referred to as *tares*. Since normally it is not possible to have a continuous sampling of the instrumental response during transport, it is obvious that the differentiation into drift and tares is a matter of convention.

It is implicit in this discussion that the largest non-systematic errors occur between stations and that the World Net data include some gross errors and site identification errors. Therefore, in order to establish a criterion for rejecting gross errors the observations are treated as gravity differences between pairs of consecutively observed stations. Also assumed is that the differences between the random components of the station errors are themselves randomly distributed. The systematic components of the station errors and the systematic errors between stations are presumed to be accounted for in the observation equation. (See 2.1.1.).

For gravimeters the largest systematic error component is the instrument scale factor. It is expressed as a linear function of the dial reading difference corrected for earth tide, dial response and, where possible, pressure and circular error. The use of higher order scale terms in the observation equation appears unjustified on the basis of our present knowledge of gravimeter operating characteristics. For the LaCoste and Romberg gravimeter, the manufacturer supplies a dial response correction curve which should linearize the readings within the error limits of the weight calibration procedure. If the response of the meter to actual changes in the gravity field is not exactly simulated by the weight calibration, the dial response curve when applied to actual reading difference will generate systematic non-linearity errors. If such errors exist, they are probably related to the design of the gravimeter sensing element or to the weight calibration procedure. The inclusion of a second (or higher) order scale term in the observation equation would therefore increase the internal consistency of an adjustment but would in fact simply correct every LaCoste and Romberg gravimeter to a mean non-linear meter. A large number of absolute measurements than is presently available is required to determine the magnitude of the non-linear scale terms. In any case the non-linearity errors are probably negligible over the central portion of the dial range. If present, they are more likely to affect the extremes of the dial response curve. Some allowance should therefore be made in any error estimates for stations at the extremities of the gravity range to account for the possible presence of non-linearity errors.

Instrument drift is considered as the linear component of the reading change between stations and is included as an unknown in the observation equation. For LaCoste Romberg gravimeters and some pendulums it is treated as a linear function of the time interval between stations. For Gulf pendulums Woollard has reported that the drift appears to be related to the heating of the pendulums during each set of swings. All time intervals between stations are therefore considered equal. The drift is treated as a function of the observation number and is expressed in units of mGal / station (*Table 2*). The non-linear component of drift (*Figure 1*) for LaCoste and Romberg gravimeters is considered to be the residual effect of vibration induced reading changes proportional to the time interval between stations plus the effect of mechanical shocks occurring as a result of improper handling of the instrument. Since vibration normally increases the gravimeter reading, the error distribution for paired forth and back measurements will be bimodal (*Figure 2*). A correction for the increased variance expected in the longer (time) ties is applied in the form of an empirical weighting function (Program STATPAK). Errors induced by shocks in transit (or instrumental malfunction) are not treated specifically in this model. It is assumed that the larger ones will be removed by the rejection limit; the smaller ones will appear as pseudo-random quantities distributed throughout the net but may have small local effects on gravity values, particularly where few ties exist.

For the purposes of determining drift the measurements are subdivided into instrument-trips, that is, sequences of measurements with the same instrument in which the same mode of transportation has been used. This sub-division has been carried out at OGST during the data collection and organization phases of the IGSN 71 project. While this sub-division is reasonable for the long range measurements no attempt has been made to differentiate the transportation modes for excentre ties which may have been observed in conjunction with the long range measurements. In any case, the basic structural unit for which scale and drift are assumed constant is the instrument-trip. Where an instrument-trip consists of a small number (less than 10) measurements it is combined (equated) with the next instrument-trip in chronological sequence simply to increase the sample size for the purpose of statistical analysis.

1.2. Weighting System and Rejection Limit

Adjustments were started with the weights on file. The estimated variances obtained from the residuals grouped by instrument-trip were used to establish the weight conversion factors for the next adjustment. In later adjustments the weight conversion factors were normalized so that the standard error of unit weight would be referred to an observation of weight 1. In recycling the adjustments we consider the weights, scale factors and the network structure as a single system affected only by the rejection limit.

The initial run in each adjustment contained a large value for the rejection limit since we had no apriori estimate of the weights. In the process of slowly lowering the rejection limit on successive adjustments gross errors were rejected; the standard error of unit weight decreased and gravity value, scale factor and weight estimates stabilized, that is, became less sensitive to changes in the rejection limit.

In later cycles of each adjustment the ΔT weighting function based on the concepts described in Section 1.1. has been applied (see also description of program STATPAK).

2. – DATA PROCESSING SYSTEM

The programs used for the adjustment of the IGSN 71 are part of a specialized system developed at the Earth Physics Branch for processing local gravity networks in Canada. The features of this system pertinent to the present work are shown schematically in *Figure 3*. Two new programs (STATPAK and COMPARE) were added to the system during the final phase of the adjustments.

The system operates on three basic files : *computed intervals, control stations* and *instruments.*

The first step in the adjustment procedure consisted of plotting the city centred ties (approximately 12, 000) using the NETPLOT program. Several series of plots were produced at varying scales; after each series the control stations which did not contribute significantly to the structure of the net were removed. The final selection of control stations for the SELNET consisted of 270 primary sites (*Figures 4* and *5*).

The second step consisted of several runs of the NETSELECT program to produce the input sub-files required for the EACS, ACS, SELNET, PENDNET and BIGNET adjustments (Section 3).

In the third step which consisted of several cycles of the NETEDIT and NETADJ programs for each network, changes were made to the input specifications after each cycle. After certain cycles, the STATPAK program was run to test for correlation between the variance of the residuals and the duration of ties (ΔT) or the interval size (ΔG).

Upon completion of the adjustments of each network the gravity values from certain cycles were compared in the COMPARE program.

The main features of NETEDIT, NETADJ, STATPAK and COMPARE are described below. Typical run times on the IBM 360/85 are given in *Table 1*.

2.1. Program NETEDIT

2.1.1. General Description

This program sets up instrument, control station, equate and drift tables, selects observations from the NETSELECT output sub-file according to the input list of control stations and instrument-trips, rejects observations, produces the observation equations, a control station and instrument file and some output specifications for NETADJ.

The general form of the observation equation for gravimeter observations is :

$$\sqrt{p_n}\ (g_i - g_j - k_m\,\Delta G_{ij} - d_m\,\Delta T_{ij} = \epsilon_{ij}\ )$$

where

p_n is the observation weight that may or may not include the ΔT weighting function,

g_i is the unknown gravity value of the i-th station,

g_j is the unknown value of the j-th control station,

k_m is the unknown scale factor for the m-th instrument-trip,

ΔG_{ij} is the milligal equivalent difference between the i-th and j-th control stations,

d_m is the unknown drift rate,

ΔT_{ij} is the time interval between the observation at the i-th and j-th control station,

ϵ_{ij} is the unknown observational error.

For pendulum observations the above equation becomes :

$$\sqrt{p_n}\ (g_i - g_j - \Delta G_{ij} - d_m\,\Delta T_{ij} = \epsilon_{ij})$$

ΔT_{ij} is coded in decimal days for all pendulums except Gulf so that the solution for d_m will be expressed in mGal/day. For Gulf pendulums $\Delta T_{ij} = 1.0$ for all observations; thus the Gulf drift rate will be expressed in mGal/station. This is according to the behaviour of the Gulf pendulums with time (Woollard, Rose, 1963).

For absolute measurements the observation equation becomes :

$$\sqrt{p_n}\ (g_o - g_j - \Delta G_{oj} = \epsilon_{oj})$$

where g_o is the gravity value of an arbitrary reference base.

In the actual observation equations generated by NETEDIT the unknowns consist of the corrections to trial values for g_i , g_j , k_m , d_m and ϵ_{ij} . The trial values for g_i , g_j and k_m are obtained from the input control station and instrument files respectively whilst d_m has a trial value of zero.

The NETEDIT program has provision to specify the rejection limit, the instruments for which drift is not to be included and the instrument-trips to be grouped (equated). For special purposes provision is made to specify the instrument-trips or stations for which some of the solution terms are not required. Another series of specifications produces the output in various formats.

2.1.2. Output Description

Listing - this contains the trial values for each unknown and number of times used, the instrument equate table, rejected ties and input equations (optional).

Error Messages - these identify coding errors or inconsistencies in input data or specifications. The types of errors messages vary depending on the input specifications.

Observation Equations - these are encoded on tape with sequence numbers for each unknown.

Control Station and Instrument Files - these are passed to NETADJ to be updated with new gravity values, scale factors and weight conversion factors.

2.2. Program NETADJ

2.2.1. General Description

The NETADJ program forms the normal equations and solves the system by matrix inversion or Gauss-Seidel iteration, evaluates each observation equation, prints histograms for each instrument-trip and various statistical tables.

2.2.2. Input Description

In addition to the observation equation, control station and instrument files passed from NETEDIT the input may include various option specifications depending on the type and format of output desired.

2.2.3. Output Description

Control Station File - updated control station cards are punched with adjusted g values.

Instrument File - updated scale factor cards are punched with adjusted scale factors for each instrument-trip. The weight conversion factors are computed from the variances of the residuals on each instrument trip and normalized to a mean of 1.

Observation Equations - the evaluated observation equations may be printed out (optional).

Histograms - a histogram of all residuals is plotted with class interval $0.5\,\sigma$, where σ is the mean square weighted residual. For each class the value of the corresponding normal distributions N $(0, \sigma)$, the number of weighted residuals and the contribution to χ^2 is shown. Only 13 classes are considered in the computation of the total χ^2 and the error probability.

- for each instrument-trip two histograms are plotted, one with respect to the solution mean residual (zero) and the other with respect to the mean residual for the trip. The first is tested for goodness-of-fit to a normal curve N $(0, \sigma)$ having the solution parameters and the second for fit to a normal curve having the instrument-trip parameters.

Statistics

- trial and adjusted gravity values and scale factors showing number of times used and, from matrix inversion only, the error estimate for each unknown.
- variance of the weighted residuals, input weight and weight conversion factor for each instrument-trip.
- moments of error distributions and, calculated from the t-distribution, the probability that the sample mean, the sample skew and sample excess are not different from zero.
- variance ratio tests on pairs of trips for each instrument and the probability (from the F-distribution) that the variances are homogeneous.

2.3. Program STATPAK

A special output file from NETEDIT is used as input to STATPAK. Only LaCoste and Romberg observations are accepted. These are sorted according to increasing ΔT and subdivided into 10 classes such that each class contains an equal number of observations. Two types of graphs are plotted. The first shows a correlation of variance of residual with mean ΔT for each of these 10 classes. The second shows a correlation of variance with mean ΔG for 10 classes each 200 mGal wide. From the correlation of variance with ΔT the new weight for each observation in subsequent adjustments will be given by

$$p\ (\Delta T) = \frac{S_0^2}{b_0 + b_1\ \Delta T} \cdot \begin{pmatrix}\text{instrument}\\ \text{weight}\\ \text{conversion}\\ \text{factor}\end{pmatrix} \cdot \begin{pmatrix}\text{instrument}\\ \text{weight}\\ \text{on file}\end{pmatrix}$$

where

S_0^2 is the variance of unit weight from the previous adjustment,

b_0 is the intercept of the regression line,

b_1 is the slope of the regression line.

Both types of graphs may also be produced optionally for individual instrument-trips.

2.4. Program COMPARE

This program compares the output gravity values from various adjustments, calculates the differences between g values and the resulting scale difference. This comparison may be carried out in geographical blocks if required.

3. – ADJUSTMENTS

3.1. Introduction

Three types of adjustments were carried out : centred ties in selected blocks (EACS, ACS), centred ties between world wide selected stations (SELNET, PENDNET) and all observations between actual measurement sites (BIGNET). Strictly speaking, only the BIGNET adjustment is required but due to the cumbersome size of this system and its inhomogeneity, particularly in the local (excentre) ties, the smaller selected systems were required to investigate problems related to instrument scale factors and observation weights.

The selected global network (SELNET, *Figure 4*) consists of well interconnected gravimeter, pendulum and absolute stations in which the centering corrections have been assumed error free. It was used to study the consistency of the pendulum and absolute scales and to determine, for use in BIGNET, the scale factors and weights of the most extensively used gravimeters. In order to obtain error estimates for the gravity values this system was limited in size to one which could be easily solved by matrix inversion (475 unknowns).

The selected global network of pendulum measurements (PENDNET, *Figure 5*) includes all the pendulum stations at which gravimeter observations have been made. This adjustment provided an independent means of comparing the scale of a separate pendulum adjustment with the scale of an adjustment combining absolute, pendulum and gravimeter data.

3.2. Summary of EACS adjustments (with Gauss–Seidel method)

Adj. No.	Rej. Limit (mGal) no. of obs. no. of rej.	No. of unkn. Bases Instr-trips Drift terms	Weights computed from Adj. No.	S_0 (mGal)	Approx. weight unit	Fixing Equations	Remarks
2	1.30 3958 6	335 290 45 0	as on file	±0.088	1.0	Δg Copenhagen to Johannesburg	LCR data only. Reference base Johannesburg. Great spread in estimated variances for individual instrument trips leads to large weight changes for next run.
3	0.25 4019 66	336 291 45 0	2	±0.075	1.0	Δg Copenhagen to Nairobi	LCR data only. Reference base Nairobi. Long tails of histogram in no. 2 disappeared due to rej. limit. Relative changes in scale factors range up to 10^{-4}. Some weight estimates change by a factor of 2 or more.
4	0.50 2045 1	349 305 44 0	as on file	±0.046	1.0	as in Adj. 3	Non-LCR data only. Reference base Nairobi. Output weight conversion factors range from 0.5 to 5.5. Apparently better internal consistency than LCR net.
5	0.50 2045 1	as in Adj. 4	4	±0.045	1.0	as in Adj. 3	Non-LCR data only. Weight changes are negligible. Scale factor changes all less than 10^{-4}. Small g value changes (few one-hundredths of a mGal).
6	0.50 6090 32	458 369 89 0	3 and 5	±0.075	2.1	as in Adj. 3	All gravimeters. Some g value changes up to 0.10 mGal (a few greater). Some scale factor changes greater than 10^{-4}. Weight changes 50 %.
7	0.50 6090 21	as in Adj. 6	6	±0.077	2.2	as in Adj. 3	g value changes generally 0.01 mGal or less. Negligible scale factor and weight changes.
8 NETEDIT only	0.25 6090 54	as in Adj. 6	7	STATPAK for correlation with ΔT for 3959 LCR observations gives: $r = 0.68$, $S_0^2 = 0.0048 + 0.00014\ \Delta T$.			

Adj. No.	Rej. Limit (mGal) no. of obs. no. of rej.	No. of unkn. Bases Instr trips Drift terms	Weights computed from Adj. No.	S_o (mGal)	Approx. weight unit	Fixing Equations	Remarks
9	0.25 6090 61	as in Adj. 8	7	±0.80	2.5	as in Adj. 3	Weighting function from no. 8 has been applied. Same solution as no. 7 except ΔT weighting function applied. Rather small improvement in solution. Error distribution has become more nearly normal.
11	0.30 6090 41	499 369 87 43	9	±0.078	2.7	as in Adj. 3	Drift term included for all LCR. Small changes in g values (usually less than 0.02 mGal) and in scale (less than 5.10^{-5}).
12 NETEDIT only	as in Adj. 11	as in Adj. 11	11	STATPAK for correlation with ΔT on 3975 LCR observations gives : $r = 0.78, \quad S_o^2 = 0.0052 + 0.00039\ \Delta T$.			
3	0.30 6090 39	as in Adj. 11	11	±0.082	2.7	as in Adj. 3	Weighting function from n° 12 has been applied. g value changes are less than 0.01 mGal; scale changes range up to 6.10^{-5}. Large changes in weights (up to 50 % or more for smaller weights). Output weights range from 0.2 to over 15.
14 NETEDIT only	as in Adj. 11	as in Adj. 11	13	STATPAK for correlation with ΔT on 3975 LCR observations gives : $r = 0.65, \quad S_o^2 = 0.0065 + 0.00013\ \Delta T$.			
15	0.25 6090 57	as in Adj. 11	13	±0.081	2.8	as in Adj. 3	Most g value changes less than 0.01 mGal; negligible changes in scale and weights.

3.3. Summary of ACS adjustments (with Gauss–Seidel method)

Adj. No.	Rej. Limit (mGal) no. of obs. no. of rej.	No. of unkn. Bases Instr. trips Drift terms	Weights computed from Adj. No.	S_0 (mGal)	Approx. weight unit	Fixing Equations	Remarks
1	0.5 4543 126	337 213 124 0	as on file	±0.085	1.0	Δg Fairbanks to Panama	Reference station was Fairbanks. Output weights range from 0.3 to 4.2, one at 8.9. Only LCR observations are present.
2	0.5 4543 73	325 213 112 0	1	±0.091	1.5	as in Adj. 1	29 instrument trips were equated when less than 10 observations and scale factors within 5.10^{-5}. g value changes up to 0.1 mGal. Scale factor changes within 3.10^{-5} Weight changes within 30 %.
3	0.35 4543 94	324 213 111 0	2	±0.088	1.7	as in Adj. 1	g values change less than 0.02 mGal. Scale factor changes were less than 10^{-5}. Weight changes are generally small but a few up to 30 %.
4	0.35+0.008 ΔT 4543 110	435 213 111 111	3	±0.092	1.8	as in Adj. 1	Inclusion of drifts terms improved many individual instrument-trip histograms but general histograms still show excess of near-zero errors. Drift terms are generally positive. Small changes in g values, scale factors and weights.
5 SETEDIT only	0.35+0.008 ΔT 4543 104	as in Adj. 4	4			STATPAK for correlation with ΔT gives :	$r = 0.87$, $S_0^2 = 0.0067 + 0.00055\ \Delta T$.
6	0.35+0.008 ΔT 4543 106	as in Adj. 4	4	±0.092	2.0	as in Adj. 1	Weighting function from no. 5 has been applied. Most g value changes are less than 0.01 mGal. A few scale factors change up to 12×10^{-5}. Only the higher weights change. Output weights range from 0.2 to 32.0. Fewer near-zero errors in the general histogram.
7 SETEDIT only	0.35+0.008 ΔT 4543 109	as in Adj. 4	6			STATPAK for correlation with ΔT gives :	$r = 0.78$, $S_0^2 = 0.0081 + 0.00018\ \Delta T$.
8	0.27+0.002 ΔT 4543 145	as in Adj. 4	7	±0.089	2.1	as in Adj. 1	Weighting function from no. 7 has been applied. Most g values change less than 0.03 mGal. Scale factors change up to 5.10^{-5}. Weight changes within 20 %.

3.4. Summary of SELNET adjustments

Adj. No.	Rej. Limit (mGal) no. of obs. no. of rej.	No. of unkn. Bases Instr. trips Drift terms	Weights computed from Adj. No.	S_o (mGal)	Approx. weight unit	Fixing Equations	Remarks
1-3 Seidel	1.0 down to 0.5 7140 116 max	465 272 193 0	as on file	±0.179 max	1.0	all pend trips plus absolute measurements	Used to improve trial g values and scale factors and finally to equate 81 trips. Ten pendulum ties rejected in run no. 3.
4 Seidel	0.35 5874 211	571 265 153 153	as on file	±0.086	1.0	11 abs. g's only	Restarted with wts = 1.0. Drift terms included for all instruments. Output weights range from 0.3 to 12.0. Scale factors change generally within 10^{-4}. g values change up to 0.01 mGal.
5 Seidel	0.25 5846 257	456 265 152 39	4	±0.084	2.0	as in Adj. 4	One more trip equated. Drift requested only for instrument-trips greater than 0.005 mGal/hr in no. 4. Small output weight changes. Scale factors change less than 3.10^{-5}. Most g values change less than 0.02. General histogram shows excess of near-zero errors.
10 NETEDIT only	0.25 5846 290	398 265 110 23	5				STATPAK on 5846 observations for correlation with ΔT gives : $r = 0.85$, $S_o^2 = 0.0057 + 0.00031\ \Delta T$. It has been applied only to adjustment no. 11. See Fig. 6.
6 Seidel	0.25 7161 358	485 270 151 64	pend = 0.2 others from Adj. 5	±0.088	1.3	all pend trips	This run used only to establish weight conversion factors for pendulums. Rejection limit probably too small.
7 Seidel	0.25+0.002 ΔT 7106 314	as in Adj. 6	6	±0.083	1.3	as in Adj. 6	Paris absolute value used for datum. Since pendulum weights are improved only 15 pendulum Δg's rejected. Pendulum weights still not stabilized. Scale factor changes are negligible.
8 Seidel	0.25+0.002 ΔT 7110 234	as in Adj. 6	7	±0.069	1.0	as in Adj. 6	g values change up to 0.02 mGal. Weight and scale factor changes are negligible. Drift terms for Cambridge pendulums very small and therefore not used in subsequent runs.
9 Seidel	0.25+0.002 ΔT 7121 187	474 271 151 52	8	±0.069	1.0	all pends plus absolute	Small weight changes (less than 15 %). Very small consistent changes in scale factors (10^{-5}). System appears stable. STATPAK on Edit no. 10 run at this point.
11 Matrix Inversion	0.25+0.002 ΔT 7208 226	as in Adj. 9	9	±0.069	1.0	as in Adj. 9	Weighting function has been applied (after no. 10). Most g values changes are less than 0.02 mGal. Only 3 changes greater than 0.04 mGal. No significant change in weights or scale factors. Only 11 pendulum Δg's rejected.

3.5. Pendulum Net (PENDNET) Adjustments

3.5.1. Introduction

A separate adjustment of the pendulum observations has been carried out to determine if the scale differs significantly when the pendulums are not adjusted in combination with gravimeters.

3.5.2. PENDNET n° 1

A first adjustment was performed using matrix inversion on the 99 pendulum stations and 1274 corresponding pendulum observations. As in the SELNET adjustments, the Δg's observed with each different pendulum pair of the same apparatus have been considered as independent observations (and therefore not averaged) but the various pairs have been equated within trips. Layovers (measurements repeated in sequence at the same site) have been included to aid in the drift computation. Equal weight was assigned to all the observations. Only 5 observations were rejected (unweighted residuals greater than 5 mGal). Drift terms were included in observation equations for all the apparatuses except the Cambridge and DO for which drift had been found to be insignificant from SELNET adjustments.

The standard error of unit weight was ± 0.628 mGal. Most of the drift terms appear to be insignificant (two-tailed-t-test for null hypothesis at 5 % test level). Those for trips GF08 and GF09 with the K-set Gulf pendulums (about + 0.35 mGal per observation) are the highest significant rates. Some of the histograms for the individual trips appear rather skewed; the general distribution of the residuals has an excess of near-zero errors and rather long discontinuous tails, so that the need for recycling with new weights is indicated.

The variances estimated from the residuals grouped by instrument and trip produce the weight conversion factors, that, after normalization, range from 0.08 to 6.01. Apart from these two extreme values, the rest of weights range from 0.18 to 2.25.

The comparison of the adjusted g values from PENDNET n° 1 and SELNET n° 11 shows that 3 stations differ by more than 1.0 mGal, while most of the other stations lies within ± 0.3 mGal. There appears to be a scale difference of about 5.10^{-5} (PENDNET n° 1 having the smaller scale).

The greatest differences appear at stations with small numbers of connections or where anomalous observations were already noted in the original papers (Antofagasta and Punta Arenas, see Woollard and Rose, 1963). The only exception occurs in Lima (used 22 times) where the deviation of 1.4 mGal, which also causes Quito to deviate by 0.7 mGal, is apparently related to an environmental error in the 16 Cambridge pendulum ties of trip CB07. This will not likely affect the scale comparison since the net is sufficiently well constructed to limit the propagation of this error beyond Quito.

The next cycles of the pendulum net adjustment (PENDNET n° 2, n° 3) were carried out in two ways, one using g values from SELNET n° 9 to determine the rejections and one using the g values from PENDNET n° 1. This permitted an evaluation of the effect of the rejection limit in a net where the number of degrees of freedom is rather low with respect to the number of unknowns and the dispersion of the observations rather high.

3.5.3. PENDNET n° 2

This adjustment has been carried out by applying the weights derived from PENDNET n° 1 and a rejection limit of 3 σ (± 1.90 mGal for weight = 1). The reference g values were taken from SELNET n° 9.

Since the pendulum ties which are apparently inconsistent with the gravimeter net are rejected, this type of solution is in some way equivalent to a tare-and-creep gravimeter comparison method. It is therefore not surprising that a great number of observations (9.4 %) were rejected during this run. This adjustment shows only that a no-scale-difference hypothesis is not disproved but it cannot prove that the scale is really in agreement since it cannot be considered as entirely independent from the SELNET adjustments.

The estimated standard error of unit weight from this adjustment was ± 0.39 mGal. Weight changes were small for all the trips except for GF 12, GF 13, GF 14 (equated) where the change was by a factor of 2.2.

The average standard error of the g values for stations observed 10 times was ± 0.18 mGal, while for stations observed 100 times or more the average was ± 0.06 mGal.

3.5.4. PENDNET n° 3

This run was made with the weights and g values derived from PENDNET n° 1. The rejection limit was set to ± 2.5 mGal for weight = 1, (corresponding to 4 σ) as it was considered that the weights were not yet stabilized. The number of rejections was 29 (2.3 %). The standard error of unit weight was ± 0.45 mGal, and the standard errors of the adjusted gravity values average about ± 0.45, ± 0.20, ± 0.15, ± 0.06 mGal for stations observed 2, 10, 20, 100 times respectively. Drift terms generally have smaller standard errors but about the same values as those from PENDNET n° 1. G value changes from PENDNET n° 1 are quite high as expected since input weights are quite different. The weights estimated from PENDNET n° 3 on output do not differ significantly however from those assumed on input (except for the trip GF 12, having only 12 ties).

The comparison of the g values from PENDNET n° 3 and SELNET n° 11 is plotted in *Figure 10*.

3.6. General solution (BIGNET)

The BIGNET adjustments incorporated virtually all the data (25,000 observations, 2019 control stations) in the uncentred version of the data files. Pendulum data were not included since instrument scale factors and weights were fixed (section 3.1) at the values obtained in SELNET n° 11. For those instrument-trips not used in SELNET n° 11, scale factors and weights were obtained from the final ACS and EACS adjustments. Correction factors for the scale of these instrument-trips were computed from linear regression lines through the g values plotted in *Figures 7* and *8* respectively. Weights were converted according to the inverse ratio of the estimated variances of unit weight from individual adjustments and SELNET n° 11.

The starting gravity values were taken from the OGSI control station file. A rejection limit of 0.35 mGal (5 σ estimated from SELNET) was used for the initial run. Since the number of rejections was not large (1.2 %) it is unlikely that the input g values biased the adjusted values. On the second cycle of the adjustment, using the same rejection limit and the output g values from the first, rejections dropped to 1 % of the total number of observations. G values changes were generally in the ± 0.01 mGal range.

The next two cycles (BIGNET n° 3 and n° 4) again employed a 0.35 mGal rejection limit and included the ΔT weighting function derived for the SELNET, i.e. p $(\Delta T) = 0.0042 / (0.0035 + 0.0031\ \Delta T)$. In BIGNET n° 4, the maximum g value change from the previous cycle was 0.05 mGal. Less than 1 % of the ties were rejected. The standard error of unit weight was ± 0.036 mGal corresponding to a weight of approximately 1.

As expected, the results of BIGNET n° 4 pointed out several discrepancies and structural weaknesses in the excentre nets. These result from a shortage of information in the observation file, errors in site designation or poor observing procedures in the field. There is no way to resolve these problems until new field observations are made. About 60 stations had a difference with respect to the separately adjusted excentre nets of 0.05 mGal or more.

4.– COMPARISON OF g VALUES AND SCALE

The EACS, ACS, SELNET and BIGNET adjustments were compared for the purpose of evaluating the effect of structure (areal distribution of ties and weight formulation) on the gravity values. The comparison of these adjustments with the pendulum adjustment (PENDNET) and with the observed absolute values, permits an estimation of the maximum scale error due to the unique structure of each net.

The comparisons of the final EACS and ACS adjustments with the SELNET no. 11 (absolute + pendulum + gravimeter) adjustment (*Figures 7* and *8*) show that the relative dispersion in EACS g values is fairly high. The implication is that the EACS system does not have a well balanced structure due to the rather poor connections between the European and African blocks. A better structure is achieved in the SELNET. The ACS appears to be highly consistent with the SELNET ; nearly all the residual differences after rescaling the ACS to SELNET are within ± 0.05 mGal. It is notable that the southernmost stations in South America tend to have g values in SELNET systematically greater by about 0.05 mGal than those in ACS adjustment. This is not surprising in view of the poor structure of the net in this area. The scale difference in *Figures 7* and *8* has no practical significance, as it depends only on the rather arbitrary fixing equations that have been assumed in the EACS and ACS system.

Figure 9 shows a comparison between the global adjustment (SELNET no. 5) scaled by the absolute values and SELNET no. 8 scaled by pendulums. With the exception of 3 poorly connected points (Bermuda K, Tananarive, and Beloit) the gravity values show a systematic agreement to better than 2 parts in 10^5 with a residual dispersion of less than ± 0.04 mGal.

Figure 11 compares the gravity values obtained from the general solution (BIGNET n° 4) with those which are common to SELNET n 11. No systematic scale difference is apparent. The more prominently deviating stations are shown by name and nearly all are characterized by structural weaknesses in long range ties or in excentres.

5. – STABILITY OF THE g VALUES

Changes in the gravity field with time at a given point, if they exist, are presumably averaged by the adjustment procedure. Therefore the observation residuals at one point should be correlated with the time of observation if the change occurs only at that point.

An attempt to detect changes in gravity from the IGSN 71 data has been made by analysing the unweighted residuals on all ties to or from Mexico City, a site well connected to several different stations and having suspected crustal movements. A plot of the residuals versus time of observation, does not show any systematic trend. The residuals are however characterized by a considerably greater dispersion than might be expected possibly due to short period instability in the Mexico City sites.

6. – CONCLUSIONS

a) Gravimeter scale standards based upon pendulum or upon absolute measurements agree to better than 1 part in 50 000.

b) The determination of the gravity values is not critically affected by the choice of weighting criteria or rejection limits due to considerable redundancy in the observations. In a few cases, particularly at the extremities of the net where the structure is weak or where the stations are mainly interconnected by a few long ΔT ties the ΔT weighting function may have an appreciable effect.

c) The accuracy of the gravity values is limited by the distribution (structure) of the measurements and an imperfect knowledge of gravimeter performance (non-linearity) characteristics. A series of absolute measurements at, say, 500 mGal intervals over the gravity range of the earth would be required to provide a sufficiently accurate external comparison for the solution of the gravimeter non-linearity problem.

d) Error estimates derived from adjustments reflect only the internal consistency of the data and are too low as estimates of the true errors if some systematic errors have not been taken into account in the adjustment model.

e) No significant change in the gravity value with time could be detected on the basis of an analysis of all ties to one point in the net. This does not mean that such changes are unlikely to occur but only that they may be difficult to detect from the IGSN 71 observations themselves. It is likely that changes in gravity will occur at least in areas of high tectonic activity and additional measurements will be required if the accuracy of the net is to be maintained.

7. – ACKNOWLEDGMENTS

The authors wish to thank Mr. R. J. Buck who developed the basic programming system and Mr. John Halpenny who carried out software development and modification for this project and assisted throughout. Dr. J. G. Tanner provided useful criticism and advice.

The work was supported by Dr. M.J.S. Innes, Chief of the Gravity Division, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa.

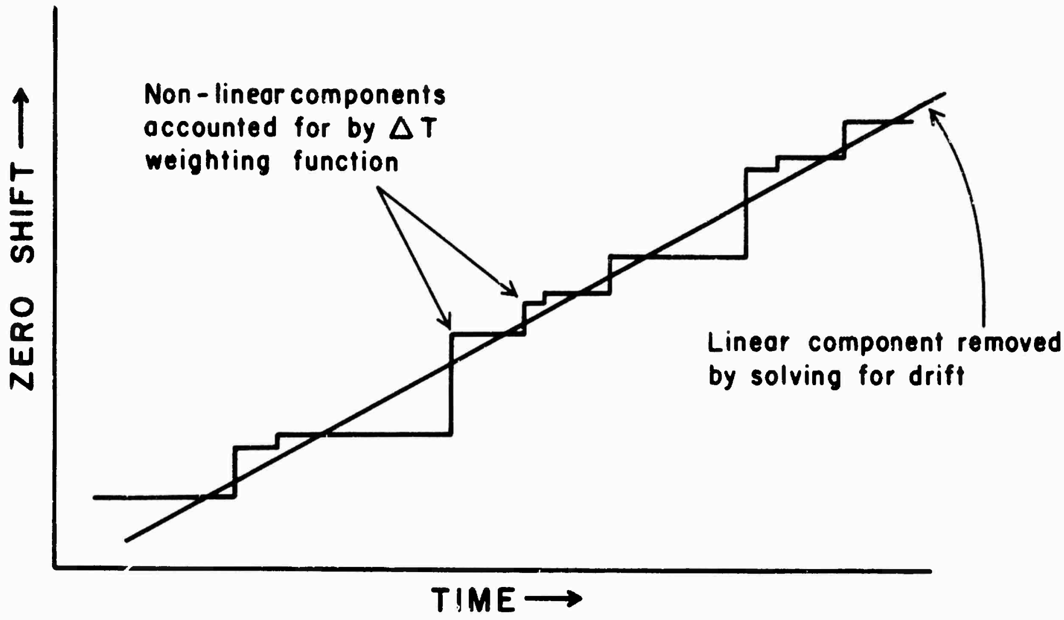


Fig. 1 : ASSUMED LACOSTE AND ROMBERG ZERO–SHIFT WITH TIME

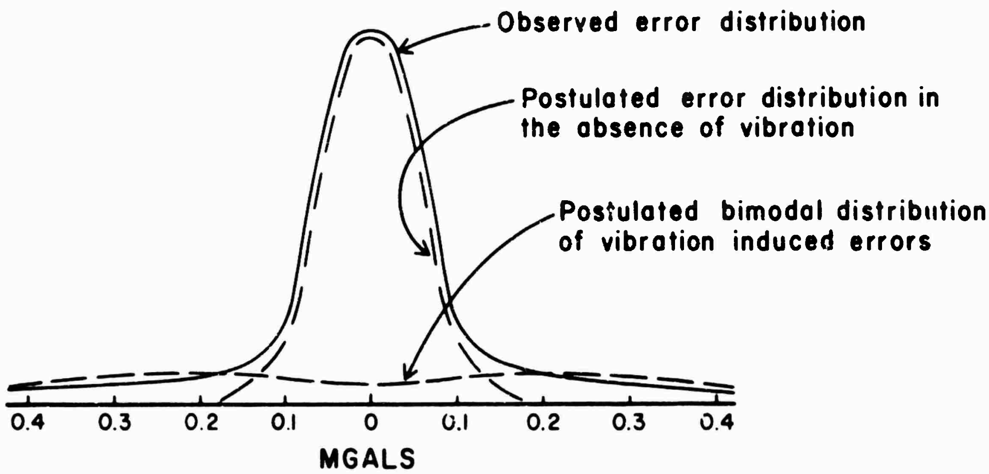


Fig. 2 : TYPICAL LACOSTE AND ROMBERG ERROR DISTRIBUTION

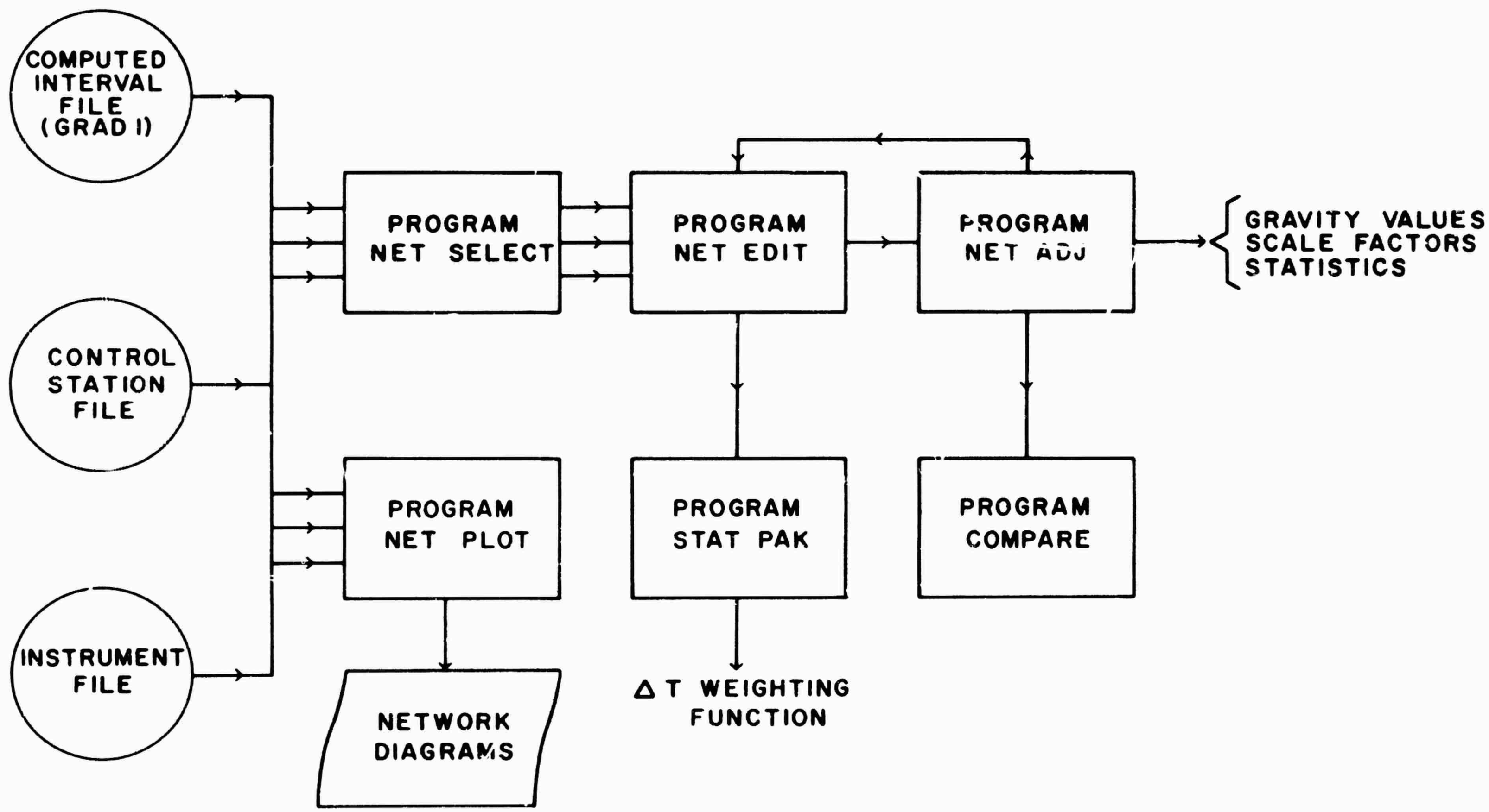


Fig. 3 : DATA PROCESSING SYSTEM

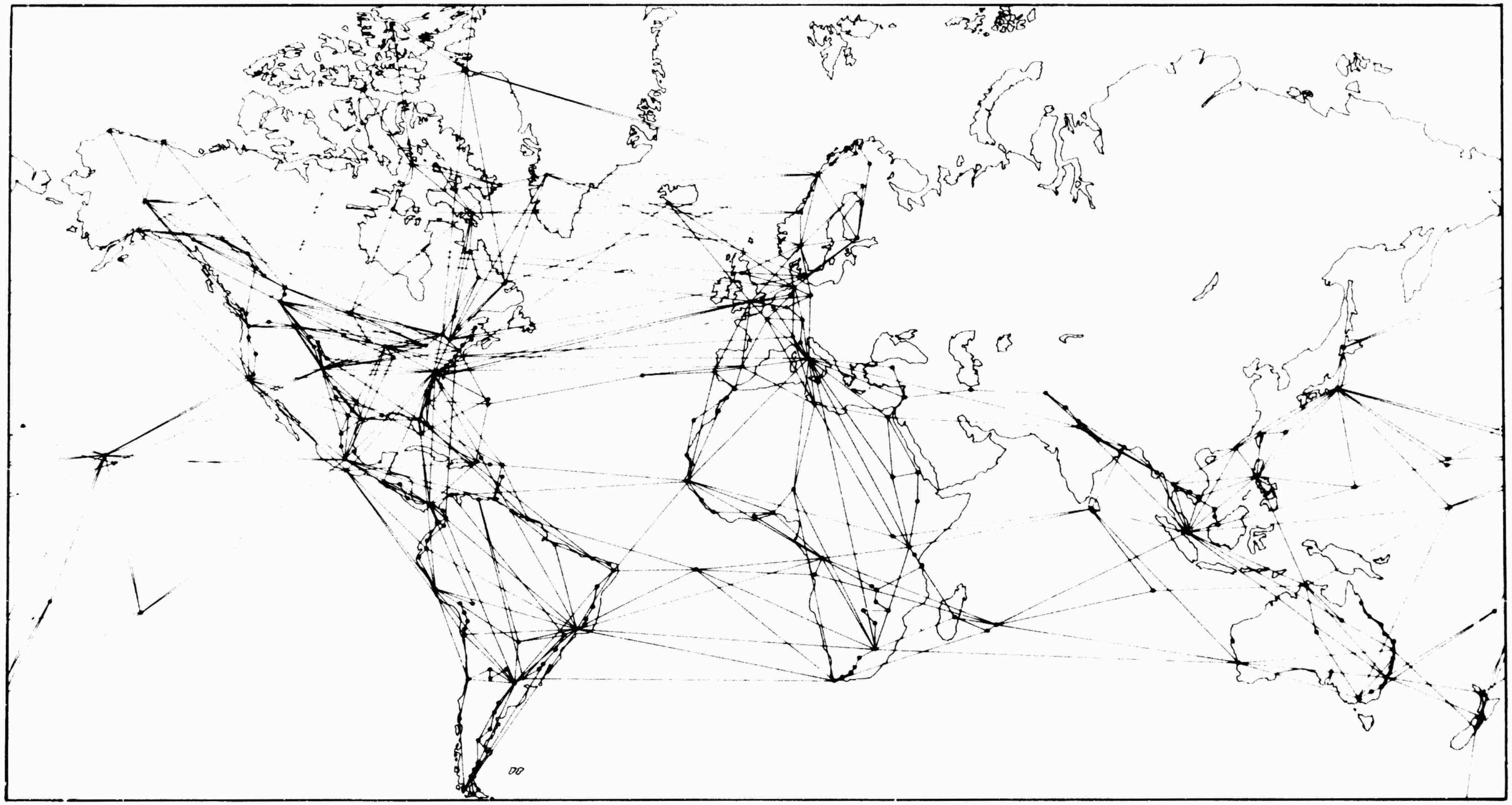


Fig. 4 : SELNET Diagram

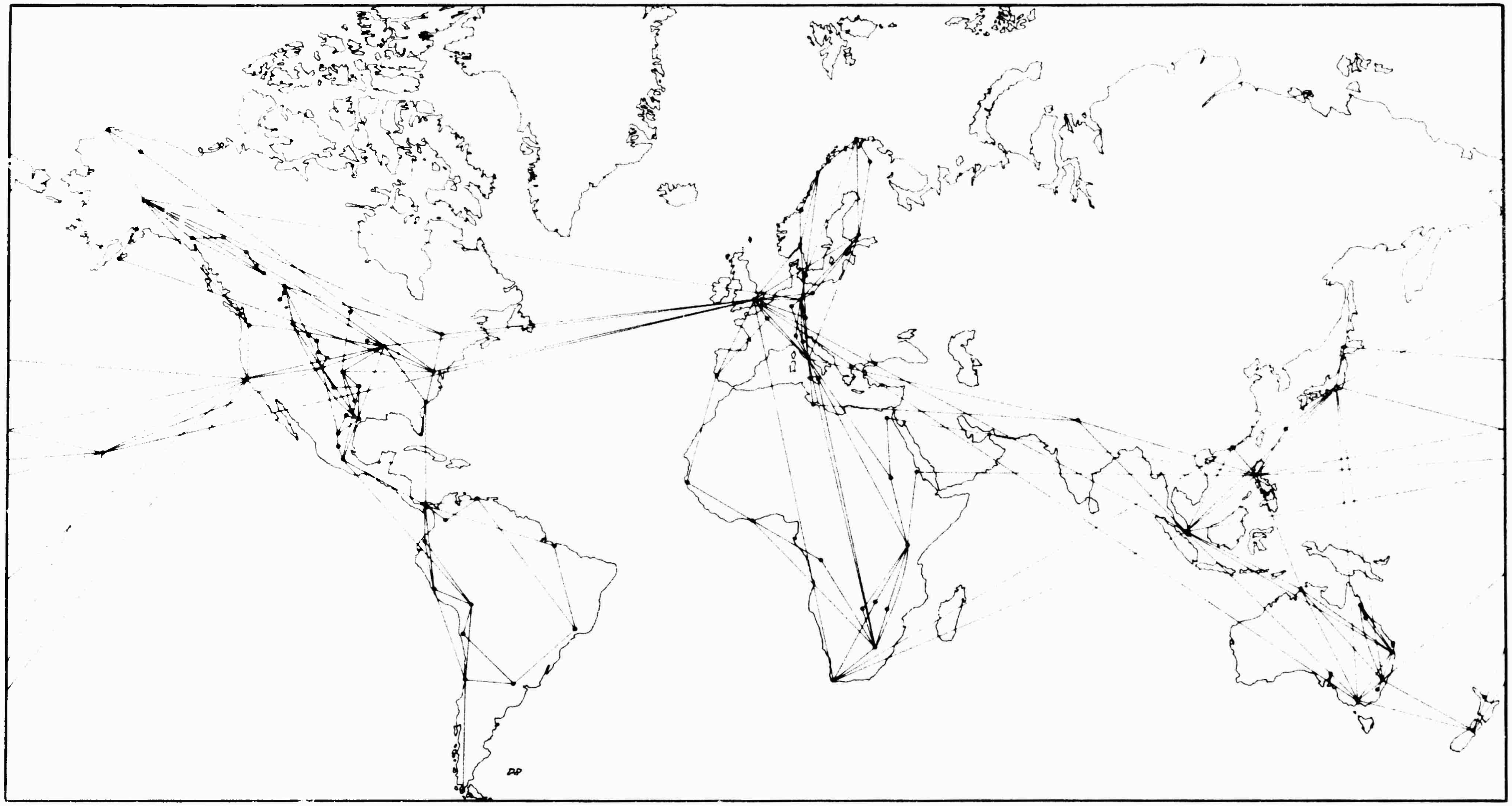


Fig. 5 : PENDNET Diagram

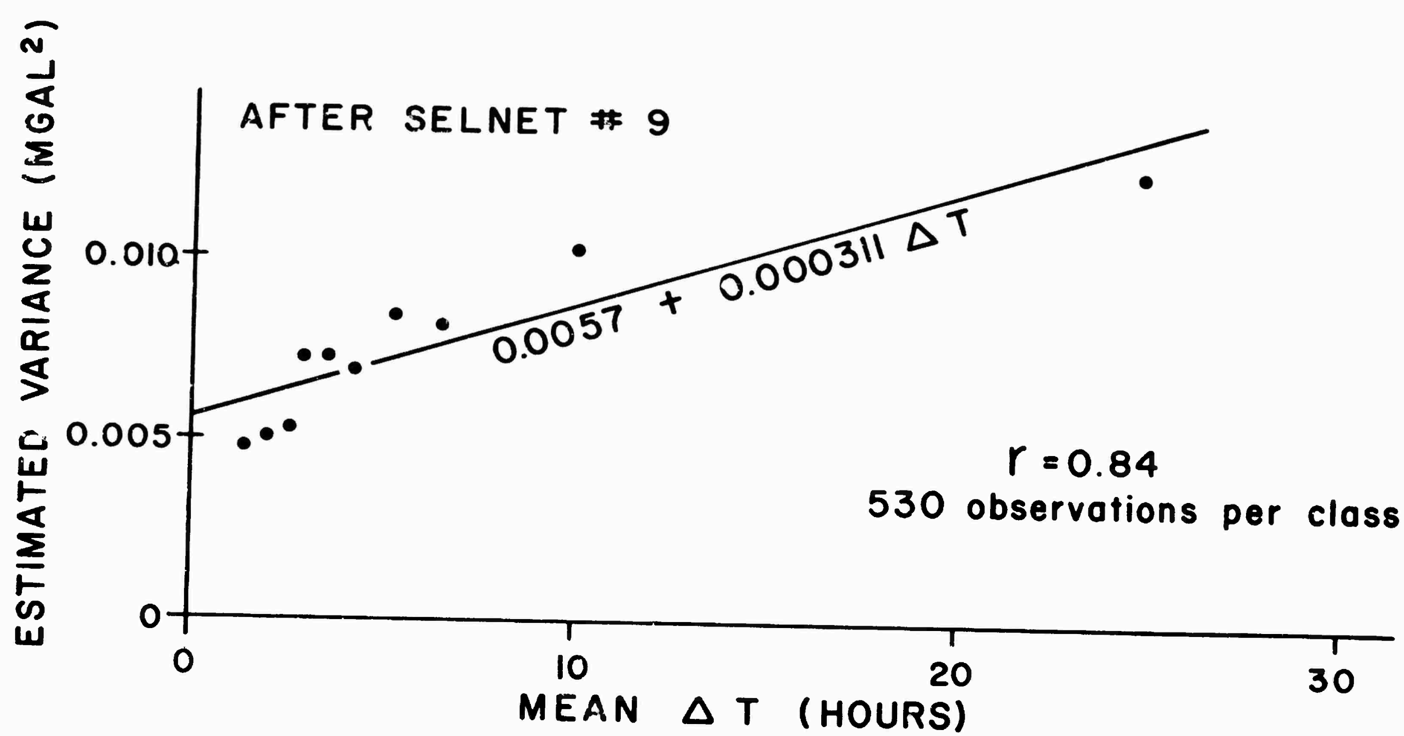


Fig. 6 : CORRELATION OF VARIANCE WITH Δ T FROM SELNET

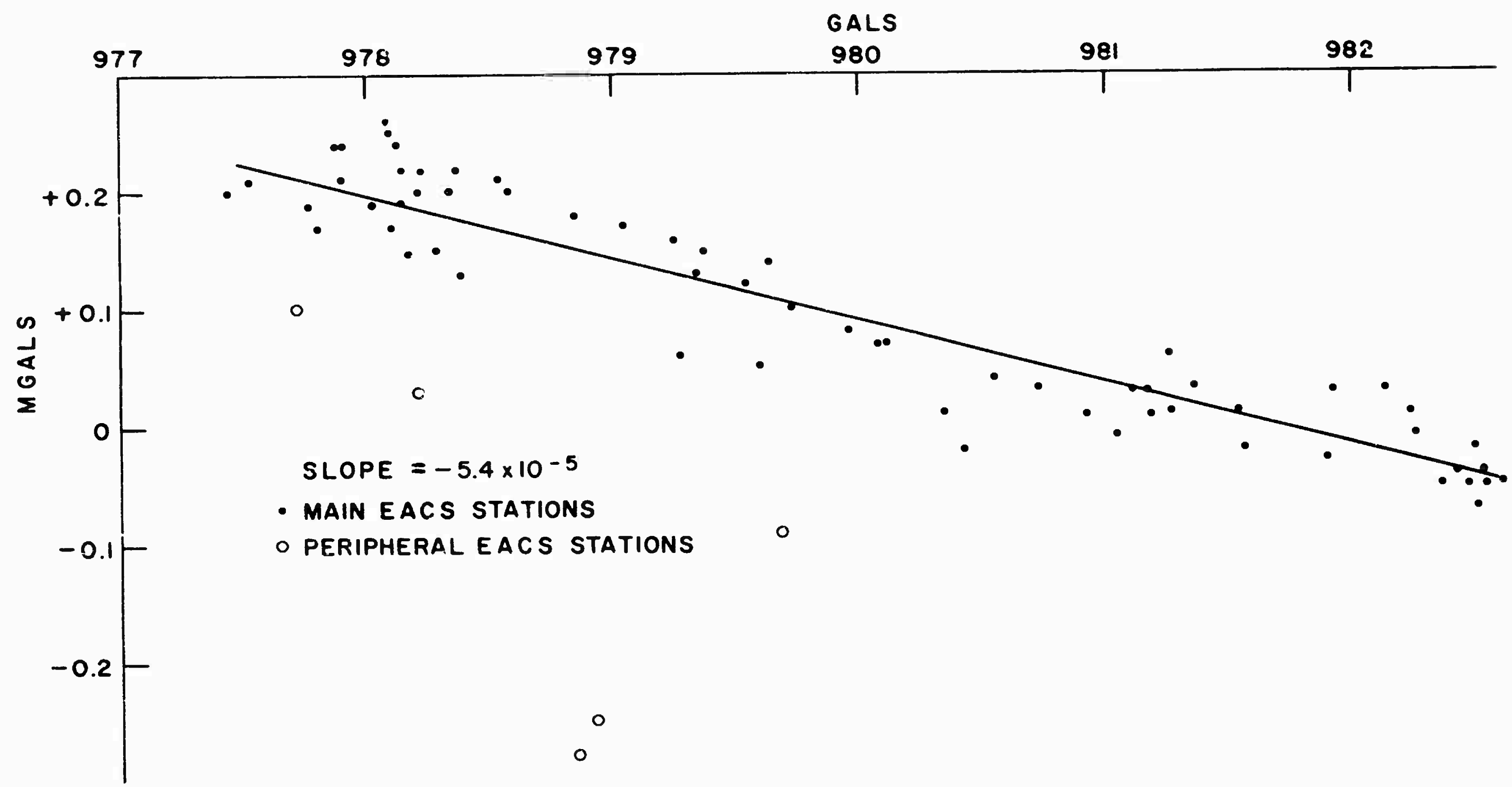


Fig. 7 : COMPARISON OF GRAVITY VALUES EACS # 15 MINUS SELNET # 11

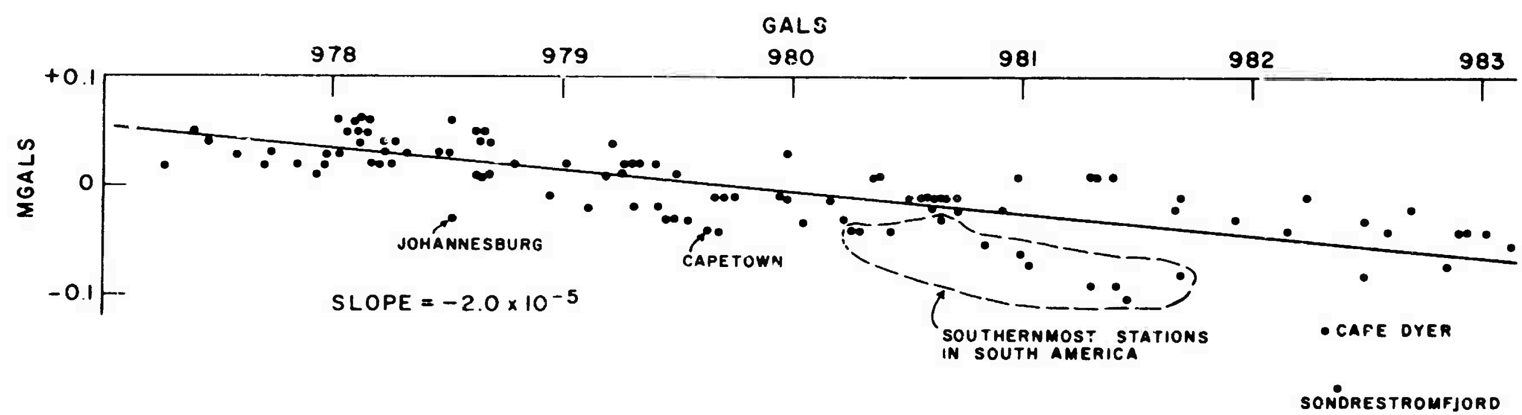


Fig. 8 : COMPARISON OF GRAVITY VALUES ACS # 8 MINUS SELNET # 11

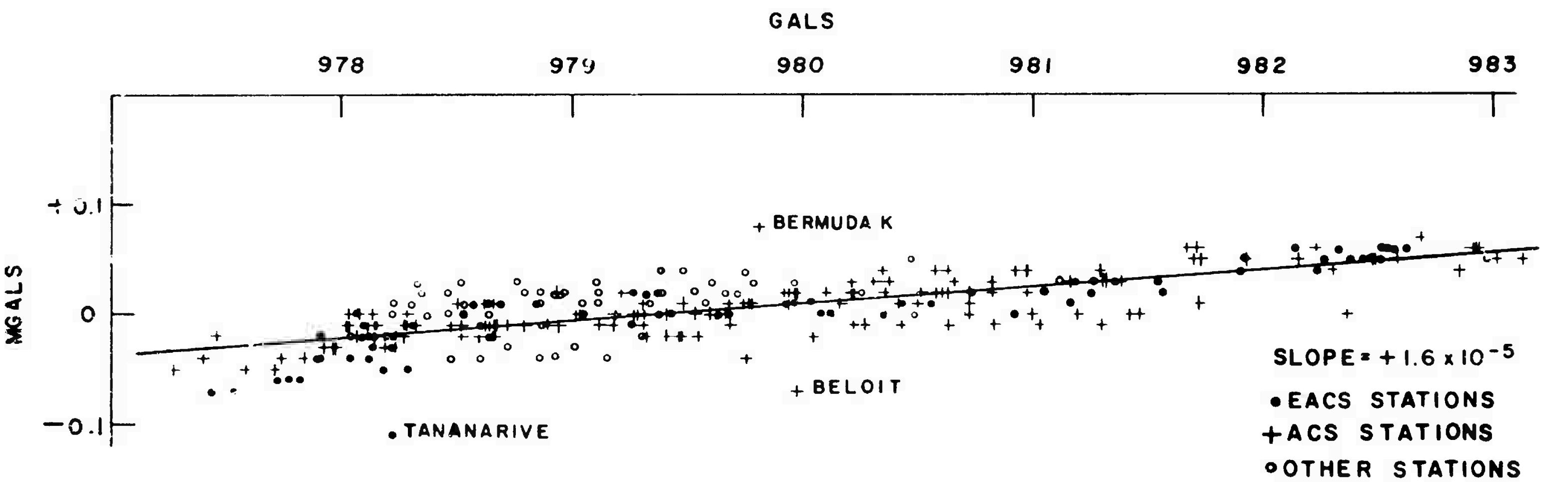


Fig. 9 : COMPARISON OF GRAVITY VALUES SELNET # 5 (ABSOLUTE)
MINUS SELNET # 8 (PENDULUM SCALE)

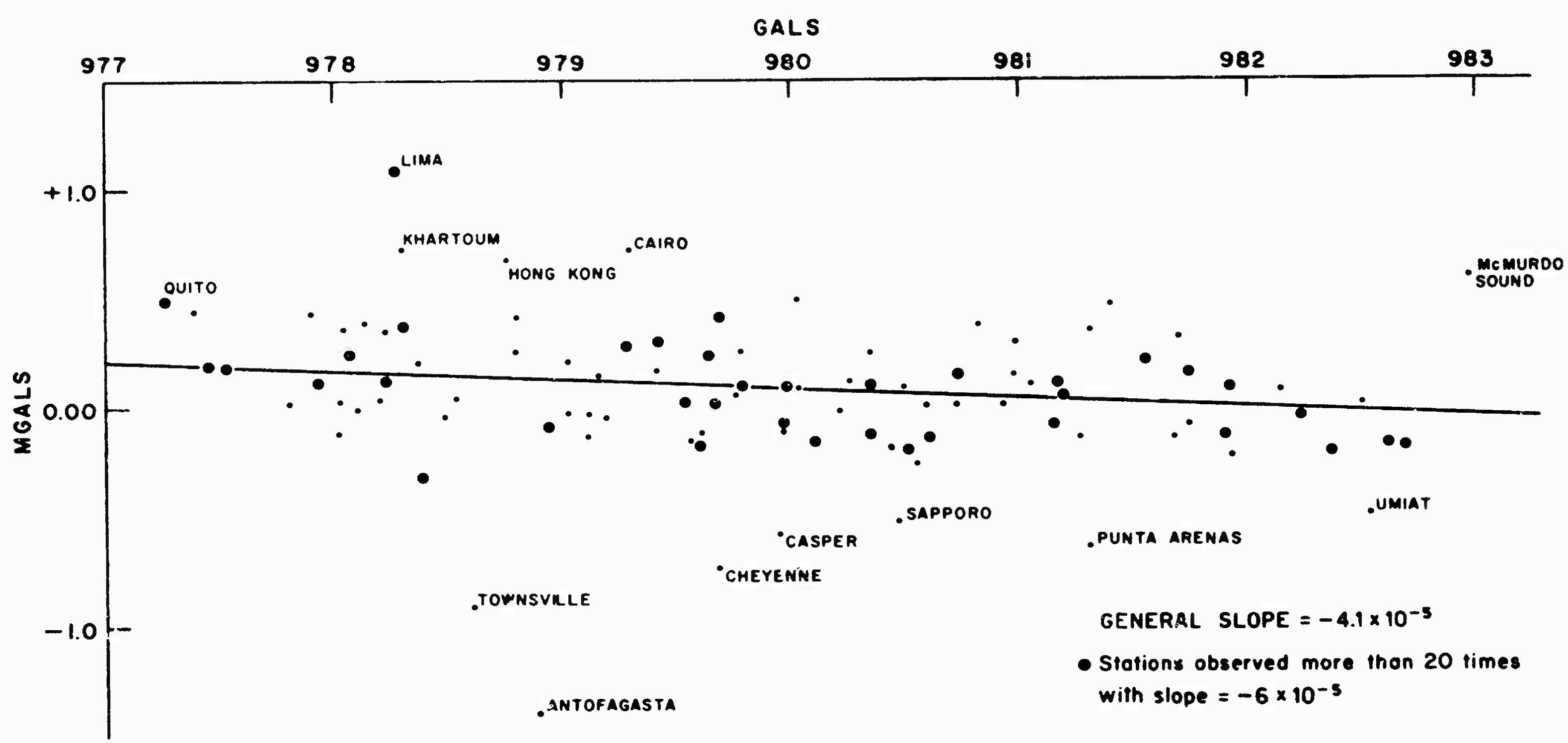


Fig. 10 : COMPARISON OF GRAVITY VALUES
PENDNET # 3 MINUS SELNET # 11

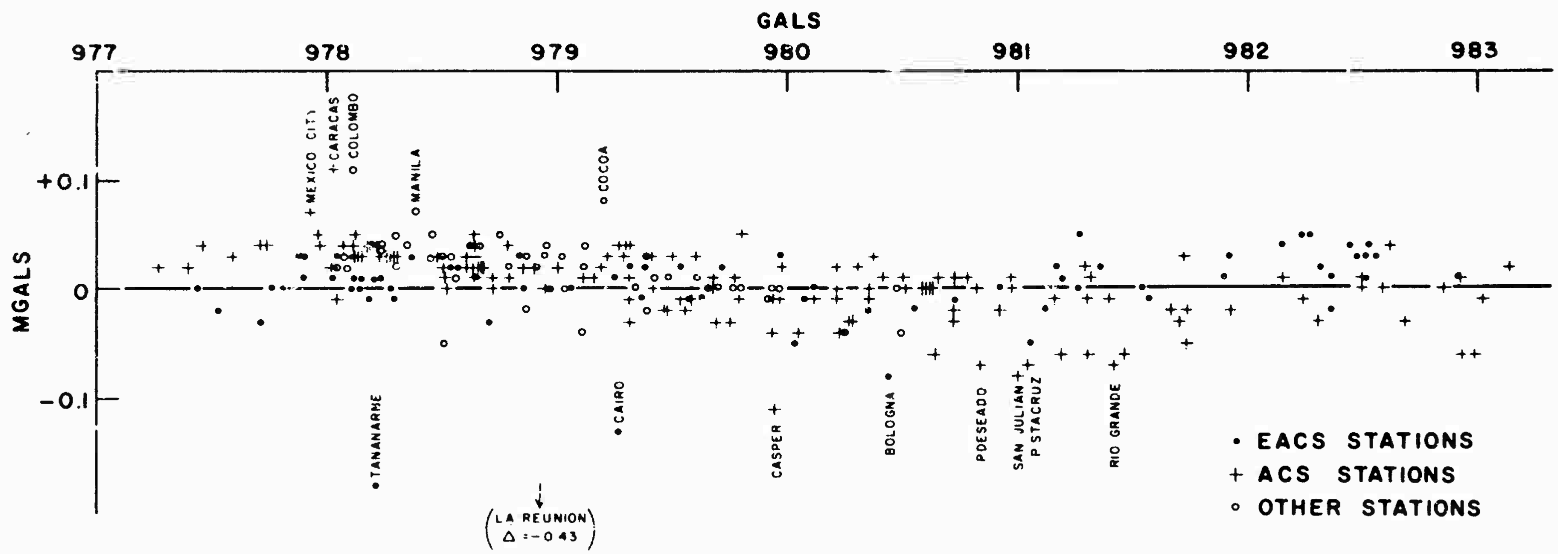


Fig. 11 : COMPARISON OF GRAVITY VALUES
BIGNET # 4 MINUS SELNET # 11

Table 1

Typical Processor Unit Times – IBM 360/85

Adjustment	No. of Unknowns	No. of Observations	C.P.U. time (in seconds)	
			NETEDIT	NETADJ
	SEIDEL			
ACS	325	4540	40	45
	435	4540	40	75
EACS	399	2050	25	30
	499	6090	40	110
SELNET	456	5850	50	80
	485	7200	55	85
BIGNET	2019	24988	250	140
	MATRIX INVERSION			
PENDNET	168	1274	35	25
SELNET	474	7200	55	410

Table 2

Typical Drift Rates for Pendulums

Trip	Drift Rates				No. of Observations
	SELNET N° 8	SELNET N° 11	PENDNET N° 1	PENDNET N° 3	
GF01K	[1] 0.063	0.064±0.144	0.163±0.131	0.045±0.194	23
GF08K	0.383	0.379±0.085	0.356±0.139	0.346±0.064	22
GF09K	0.309	0.309±0.115	0.346±0.149	0.299±0.088	18
GF01M	0.015	0.016±0.099	-0.030±0.131	0.006±0.083	24
GF03M	0.179	0.179±0.172	0.180±0.156	0.176±0.140	16
GF18M	0.160	0.160±0.071	0.017±0.191	0.178±0.174	19
GF19M	0.090	0.089±0.060	0.094±0.095	0.090±0.060	44
IT02	[2] 0.024	0.024±0.024	0.022±0.022	0.016±0.011	[illegible]0
CB01	[3] 0.016	Drift term neglected in these adjustments			33
CB10	-0.000				112
CB11	0.007				132
CB12	0.004				48
GS01	[4] 0.025	0.025±0.011	0.027±0.011	0.019±0.023	12

[1] Drift rate for Gulf pendulums in mGal/station

[2] Drift rate for Cambridge pendulums in mGal/day

[3] Drift rate for Italian pendulums in mGal/day

[4] Drift rate for GSI pendulums in mGal/day

APPENDIX V

AN ANALYSIS OF SCALE DIFFERENCES OF PENDULUM AND ABSOLUTE MEASUREMENTS USED FOR THE IGSN 71

by

T. HONKASALO

Geodetic Institute

Helsinki, Finland.

1. – INTRODUCTION

Originally pendulum measurements in the FOWGN were intended to determine the scale of the gravity calibration lines. In the course of the working period of the SSG5 the absolute gravity measurements were made with sufficient accuracy and frequency that the scale of the IGSN 71 as well as the datum could be based on them. As a result it is possible to study the contribution of the different pendulum apparatus to scale and to investigate possible sources of systematic error. This analysis was made by comparing different pendulum measurements with a preliminary adjustment of selected LaCoste and Romberg gravimeter measurements and all absolute measurements. The adjustment used was computed by Uotila at OSU in 1970 (Appendix II).

2. – ANALYSIS

The lengths of the pendulums usually change with time, e.g. due to wear of the knife edges. The change in the pendulum lengths i.e. the drift, was assumed to be linear for each trip. The average drift rate is small for Gulf M and Cambridge pendulums, but for the others the rate was frequently several tenths of a mGal per station. The average drifts and their r.m.s. values for different pendulums were as follows :

Table 1

Average drift for the pendulums

Pendulum apparatus	Average drift (mGal / stn)	r.m.s. drift
Gulf M	- 0.01	± 0.10 mGal
Gulf K	+ 0.22	± 0.33
Cambridge	- 0.01	± 0.08
Italian GC	+ 0.19	± 0.22
DO	+ 0.13	
USCGS	+ 0.09	± 0.24
Japan GSI	+ 0.16	± 0.18

For trips observed in exact ladder sequence gravity differences could be computed by taking the mean of out and back measurements. In this case the standard error of one measured gravity difference could be determined on the basis of the out and back differences. The standard error of the gravity differences on trips with an irregular observation scheme was determined by means of a special separate trip adjustment. The standard error of one observed station (σ_1) are given in *Table 2*. For Gulf and Italian pendulums the error terms refer to one pair only, whereas the values given for Cambridge pendulums refer to the mean of two to six pairs of pendulums, for DO pendulums to the mean of six pairs, for USCGS pendulums to the mean of two pairs and for Japanese pendulums to the mean of two or four pairs.

The pendulum measurements were compared with the adjusted net for each pendulum trip separately. The gravity value for each station of the trip were computed by adding the adjusted gravity differences sequentially to the gravity value adopted for the first station. For each trip the computed gravity values were compared with the adjusted net, and the scale correction coefficient and its standard error (σ_s) were computed. These are given in the *Table 2* along with the standard errors of one gravity value of the trip (σ_2) on the basis of this comparison. For each pendulum apparatus the weighted mean of different trips was computed by taking the weights

$$P = \frac{1}{\sigma_s^2}$$

Some trips with the same starting station were combined to avoid trips with very few stations.

Table 2

Pendulum scale corrections based on Uotila's preliminary (1970) adjustment

Trip code	Year	Number of stations	Standard error σ_1	Standard error σ_2	Scale correction	Standard error of scale correction σ_s	Weight P_a
Gulf M-pendulums							
GF 01	1953	26	±1.24	±0.81	0.999 735	±0.000 133	1.47
GF 02	1954	20	±0.41	±0.69	1.000 429	±0.000 141	2.04
GF 03	1955	13	±0.81	±0.72	0.999 683	±0.000 212	1.87
GF 04	1956-57	16	±0.38	±0.99	1.000 490	±0.000 197	1.00
GF 05	1957	12	±0.90	±1.78	0.999 330	±0.000 391	0.32
GF 06	1958	18	±0.38	±0.52	0.999 757	±0.000 079	3.44
GF 07	1958	10	±0.41	±0.75	0.999 786	±0.000 263	1.71
GF 09	1959	6	±0.33	±0.09	0.999 961	±0.000 059	36.85
GF 10	1960	8	±0.39	±0.31	0.999 783	±0.000 096	8.53
GF 11-14, 16	1960-62	13	±0.14	±0.10	1.000 004	±0.000 055	34.01
GF 15	1961	12	±0.19	±0.15	0.999 981	±0.000 030	23.58
GF 17	1963	13	±0.33	±0.34	0.999 795	±0.000 046	7.24
GF 18	1964	10	±0.27	±0.48	1.000 224	±0.000 051	4.07
GF 19	1965-66	15	±0.24	±0.31	0.999 904	±0.000 069	8.66
			Weighted mean		0.999 963	±0.000 043	
Gulf K-pendulums							
GF 01	1953	25	±0.97	±0.96	0.999 355	±0.000 104	1.06
GF 08	1959	8	±0.27	±0.34	1.000 194	±0.000 064	7.58
GF 09	1959	6	±0.15	±0.20	1.000 249	±0.000 072	16.73
GF 11,16	1960-62	7	±0.40	±0.34	0.999 817	±0.000 235	7.96
			Weighted mean		1.000 060	±0.000 188	
Cambridge pendulums							
CB 01	1952	7	±0.36	±0.72	1.000 631	±0.000 075	1.88
CB 02	1953	11	±0.38	±0.30	0.999 717	±0.000 171	9.33
CB 03	1954	3	±0.35	±0.84	0.999 782	±0.001 522	1.39
CB 04	1955	7	±0.38	±0.66	0.999 144	±0.000 197	2.18
CB 05	1956	4	±0.28	±0.30	1.000 203	±0.000 094	9.17
CB 06	1958	8	±0.37	±0.40	0.999 762	±0.000 066	5.67
CB 07	1958	11	±0.41	±0.19	0.999 944	±0.000 049	17.49
CB 08	1959	4	±0.14	±0.57	0.999 674	±0.000 145	2.94
CB 09	1960	5	±0.31	±0.17	1.000 212	±0.000 079	20.72
CB 10	1963	8	±0.19	±0.13	1.000 002	±0.000 031	27.55
CB 11	1964	11	±0.48	±0.35	0.999 853	±0.000 046	7.16
CB 12	1967	5	±0.27	±0.08	1.000 007	±0.000 027	39.56
			Weighted mean		0.999 996	±0.000 055	
Italian Geodetic Commission pendulums							
IT 01	1957-58	5	±0.27	±0.40	1.000 611	±0.000 415	5.59
IT 02	1959	6	±0.48	±0.48	1.000 369	±0.000 248	4.05
IT 03	1963	7	±0.27	±0.53	1.000 116	±0.000 232	3.28
IT 04	1963	4	±0.99	±0.87	1.000 648	±0.000 192	1.29
			Weighted mean		1.000 432	±0.000 129	

Table 2 (suite)

Trip code	Year	Number of stations	Standard error σ_1	Standard error σ_2	Scale correction	Standard error of scale correction σ_s	Weight P_a
U.S. Coast and Geodetic Survey pendulums							
GS 01	1952	5	±0.43	±0.51	1.000 313	±0.000 242	3.55
GS 02	1953	3	±0.19	±0.22	1.000 089	±0.000 244	14.70
			Weighted mean		1.000 202	±0.000 112	
Dominion Observatory pendulums							
DO 01	1967-68	5	±0.48	±0.07	1.000 010	±0.000 025	40.36
Japan Geographical Survey Institute pendulums							
JP 01, 02	1955-58	3	±0.43	±0.68	1.000 382	±0.000 510	2.08
JP 03, 04 JP 06, 09	1959-67	11	±0.50	±0.32	0.999 921	±0.000 0[illegible]8	8.01
			Weighted mean		0.999 937	±0.000 085	

Only a few of the computed scale corrections seem to be significant (greater than three times their standard error). The small number of observations has, however, made some standard errors uncertain. None of the weighted mean scale corrections in *Table 2* appear to be reasonably justified.

Unified computation was considered a better method than taking the weighted mean scale correction for each pendulum apparatus. Since the accuracies of trips vary considerably each trip must have a different weight. These were computed on the basis of the standard errors σ_2 and are given in the last column of *Table 2*. The weights for trips with small number of measurements are uncertain and in many cases may be over estimated. Therefore in the weight formulation account was taken of the error smoothing introduced by the original averaging process. The internal consistency for Gulf and Cambridge pendulum apparatuses was computed as ± 0.14 mGal. This estimate was used for all apparatuses to give the weight for each trip :

$$P_a = \frac{1}{\sigma_2^2 + (0.14)^2} \qquad \textit{(Table 2)}.$$

The results of the recomputation of scale corrections are given in *Table 3* below :

Table 3

Pendulum apparatus	Number of Stations	Scale correction	Standard error
Gulf M	192	0.999 972	±0.000 023
Gulf K	46	1.000 015	±0.000 069
Cambridge	84	0.999 968	±0.000 021
IGC	22	1.000 318	±0.000 134
USCGS	8	1.000 177	±0.000 153
DO	5	1.000 010	±0.000 025
GSI	14	0.999 944	±0.000 097
All pendulums	271	0.999 977	±0.000 015

On the basis of all pendulum observations scale is determined with an uncertainty of 1 part in 67 000. On the basis of the standard errors estimated by the observers for the absolute measurements (App. I), uncertainty of the absolute scale is a priori 1:44 000. Thus the pendulum observations agree in scale with the absolute measurements and their combined use to determine scale for the IGSN 71 adjustment is therefore justified.